(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 648 088 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
16.08.2001 Bulletin 2001/33

(21) Application number: **93915357.3**

(22) Date of filing: **15.06.1993**

(51) Int Cl.[7]: **A61B 5/04**, A61B 5/083, G01N 33/497

(86) International application number:
PCT/US93/05712

(87) International publication number:
WO 93/25142 (23.12.1993 Gazette 1993/30)

(54) **IN VIVO MEASUREMENT OF END-TIDAL CARBON MONOXIDE CONCENTRATION APPARATUS AND METHODS**

VORRICHTUNG UND VERFAHREN ZUR IN-VIVO MESSUNG DER ENDEXPIRATORISCHEN KOHLENMONOXYD-KONZENTRATION

APPAREIL DE MESURE IN VIVO DE LA CONCENTRATION EN MONOXYDE DE CARBONE EN FIN D EPIRATION ET PROCEDES

(84) Designated Contracting States:
AT BE DE FR GB GR IT NL SE

(30) Priority: **16.06.1992 US 899261**
15.12.1992 US 990425

(43) Date of publication of application:
19.04.1995 Bulletin 1995/16

(60) Divisional application:
00119695.5 / 1 062 909

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Description

Field of The Invention

[0001] This invention relates to methods and apparatus for in-vivo, real time measurement of end-tidal carbon monoxide concentration in the exhaled breath, more particularly to the determination of end-tidal carbon monoxide concentration in the breath of a newborn infant and to a filter unit for use in such a determination.

Background of The Invention

[0002] In most animal systems, carbon monoxide is a waste product produced in the breakdown of free hemoglobin within the blood. Ordinarily, hemoglobin is contained within red blood cells and is stable. However, aging of red blood cells and certain disease processes produce hemolysis, i.e., the breakdown of the cell wall. This produces free hemoglobin which breaks down in the blood. The carbon monoxide that is produced by the breakdown of free hemoglobin is normally excreted in the breath.

[0003] When the system is in equilibrium, the carbon monoxide concentration in the breath is proportional to the difference in the concentration of carbon monoxide in the blood and the concentration of carbon monoxide in room air. This difference in concentration is proportional to the rate of hemolysis in the blood.

[0004] The concentration of carbon monoxide in the end-tidal breath, i.e., the gas that is last expelled each breath, is presumed to be at equilibrium with the concentration in the blood. This is because the end-tidal breath contains predominantly, if not exclusively, the gas expelled from the alveoli in the lungs, which gas was within the alveoli for a time generally sufficient to equilibrate with the blood.

[0005] It is known that hemolysis and the resulting byproducts and consequences of hemolysis can be estimated or predicted from a measure of the concentration of carbon monoxide in the end-tidal breath. See Smith, D.W. et al., "Neonatal Bilirubin Production Estimated from End-Tidal Carbon Monoxide Concentration", Journal of Pediatric Gastroenterology and Nutrition, 3:77-80, 1984.

[0006] One method of analysis previously reported includes incrementally acquiring a sample of end-tidal breath and analyzing the acquired sample by mass spectroscopy or gas chromatography to determine the end-tidal carbon monoxide concentration. The sample is obtained by extracting from each of several successive breaths a portion of the apparent end-tidal breath using a syringe. The end-tidal portion of breath is determined by observing the chest movements of the infant. See, e.g., Vreman et al. U.S. Patent 4,831,024.

[0007] One problem with this technique is that it requires a skilled, trained user to obtain the end-tidal sample in successive increments based on watching chest wall movements. It also requires a trained, skilled person to operate a complex piece of analytical laboratory equipment to analyze the acquired sample. In addition, this technique requires time and personnel to transport the sample from the patient to the laboratory (or equipment) where the analysis is conducted, and then to report back to the attending physician/practitioner for a diagnosis and prescription, if any.

[0008] Another problem with this technique is that accurate assessment of the concentration difference in carbon monoxide requires obtaining good samples of end-tidal patient breath. This essentially requires that the patient have a regular, predictable breathing cycle. Thus, it can be difficult to obtain a good sample by watching chest wall movement, particularly for a new-born and for patients having irregular breathing cycles.

[0009] Chemical electrochemical sensors capable of measuring carbon monoxide concentrations in the range of interest, 0 to 500 parts per million (ppm), are commercially available, eg, model DragerSensor CO available from Dragerwerk, Lubeck, Germany. However, such sensors are sensitive to many other gases as well as carbon monoxide, and are therefore susceptible to error. Another problem with such sensors is that the measurement dynamics of the sample gas transport through the gas permeable membrane and oxidation-reduction in the electrochemical cell results in a relatively slow response time such that discrete samples of the end-tidal breath must be obtained and analysed to determine the end-tidal carbon monoxide concentration.

Summary of the invention

[0010] According to a first aspect of the present invention there is provided an apparatus for monitoring a patient's end-tidal gas flow during breathing characterised by:

a first gas detector for monitoring the concentration of a first selected gas in a gas sample and having an output corresponding to the monitored first selected gas concentration;

a first monitoring and determining means for monitoring the patient's breathing and determining the ratio of the patient's end-tidal breath portion to inspired air as a duty cycle and having an output corresponding to the deter-

mined duty cycle;

first providing means for providing a sample of room air to the first gas detector for measuring a background concentration of the first gas;

second providing means for providing a sample of the patient's breath to the first gas detector for measuring a breath sample concentration of the first gas in the patient's breath; and

first receiving and determining means for receiving the output of the first gas detector and the first monitoring means and being arranged to determine the end-tidal concentration of the first gas in response to the determined duty cycle, the determined background concentration of the first gas in room air, and the determined breath sample concentration of the first gas in the patient's breath.

[0011] According to second aspect of the present invention, there is provided a method of measuring end-tidal carbon monoxide concentration in expired breath characterised by the steps of:

(a) measuring the carbon monoxide concentration in ambient room air (CO_{room});

(b) sampling the patient's breath over a first period of time;

(c) measuring the carbon monoxide concentration (CO) in the sample patient's breath during the first time period;

(d) determine the duty cycle of the end-tidal portion of the patient's breath during the first time period; and

(e) determining the end-tidal carbon monoxide level based on the determined duty cycle, the measured concentration in ambient room air (CO_{room}), and the measured Carbon monoxide concentration in the patients breath during the first time period (CO).

[0012] It is thus possible to provide an improved non-invasive apparatus and method for measuring carbon monoxide concentration in the end-tidal breath, and to provide an apparatus and method that operate in real-time. Such apparatus and methods may be used in determining the rate of hemolysis from the concentration of end-tidal carbon monoxide.

[0013] Furthermore the apparatus and methods for measuring end-tidal carbon monoxide do not require a highly skilled, trained individual to obtain and determine the measure, nor do they require incrementally acquiring samples of end-tidal breath during successive respiratory cycles.

[0014] Advantageously an embodiment of the present invention provides a portable, easy-to-use apparatus that can be used in a nursery, a physician's office, a hospital, a clinic, and a mobile clinic for measuring end-tidal carbon monoxide in real time, for assessing the likelihood of elevated levels of hemolysis for immediate entry on the patient's record and prescription of an appropriate remedy.

[0015] Preferably an end-tidal carbon monoxide monitor has a replaceable filter unit for use with different patients, and for replacing consumed gas filtering components. Advantageously the filtering unit is an inexpensive disposable filter unit.

[0016] Preferably keyed bulkhead fittings are provided on the monitor for receiving the filter in the correct orientation and to provide for proper flow path interconnection and operation of the disposable filter in the monitor.

[0017] In accordance with this invention, there is provided an apparatus, sampling methods, and analysis techniques for measuring the concentration of end-tidal carbon monoxide in breath, particularly in new-born and premature infants. Broadly, the invention concerns determining the concentration of end-tidal carbon monoxide based on a measure of the room air carbon monoxide concentration, a measure of the average carbon monoxide concentration for a breath sample over a period of time, and a determined ratio of the end-tidal breath to inspired air for the sampled portion.

[0018] The present invention is based in part on the discovery that accurate assessment of end-tidal carbon monoxide concentration may be obtained based on knowledge of the fraction of the gas sample that is end-tidal gas. Thus, an embodiment of the present invention is able to avoid selectively sampling small samples of end-tidal breath over successive respiratory cycles to obtain a sufficiently large end-tidal breath sample, which incremental sampling is problematic. Further, an embodiment of the invention advantageously uses a conventional carbon monoxide detector, which has a response time that is not fast enough to distinguish carbon monoxide in end-tidal breath from carbon monoxide in inspired air, to derive the end-tidal carbon monoxide concentration in real-time. More particularly, a conventional carbon monoxide detector can be used to obtain the average carbon monoxide concentration level during breathing, which average value can be related to the end-tidal value based on the determined ratio of end-tidal to inspired breath. Preferably, the most common interfering substances from a sampled breath are removed from the sample by a con-

sumable filtration medium so that these substance do not affect the measurement. The present invention also applies to gas components of exhaled breath other than carbon monoxide, which gas components cannot be directly monitored because of the slow response time of available gas detectors.

[0019] A particularly useful feature of the present invention concerns using a second gas component of the breath, other than the first gas component whose concentration is being monitored, to determine the ratio of the end-tidal breath to inspired air. The relative concentration level of the second gas during respiration is monitored and the ratio or duty cycle of the end-tidal portion of the sensed concentration waveform relative to the inspired air is determined. A sensor for detecting the level (or concentration) of the second gas having a time response that is fast enough to distinguish the end-tidal breath concentration from the inspired air is preferably used. One suitable gas component is carbon dioxide, which has a large, distinctive change in concentration with breathing. Other gases may be used, eg hydrogen, oxygen, or some combination of gases, eg carbon dioxide and hydrogen.

[0020] The determined end-tidal carbon monoxide concentration may be used by a physician or other suitable health care provider to evaluate the rate or relative level of hemolysis occurring in the infant. The evaluation is typically made by comparing the determined end-tidal carbon monoxide concentration to known or pre-selected standards. For example, when measured soon after birth, the end-tidal carbon monoxide range 0.6 - 1.9 µl/l is considered normal and the range above about 2 µl/l is considered at risk. Premature infants have both a higher risk of neonatal jaundice and a higher normal range of end-tidal carbon monoxide.

[0021] Preferably the disposal filter unit is an assembly which directs the gas flow through the monitor and has two distinct flow paths. One flow path provides for receiving the breath flow sampled at the patient into the monitor, more specifically, from the nasal canula to the carbon dioxide detector. The second flow path contains the consumable filtration medium and provides a flow path between the carbon dioxide sensor and the carbon monoxide sensor.

[0022] In a preferred embodiment, the assembly is formed of a body having three flow paths (also called lumens) extending from one end to the other and a tube segment that is used to connect two of the flow paths at one end of the body. The consumable filtration medium is located in one of the two lumens connected by the tube segment. Thus, the tube segment provides for a gas flow path from the carbon dioxide detector, through the consumable filtration medium, and to the carbon monoxide detector. Preferably, the three lumens are straight and have longitudinal axes that are In the same plane. More preferably, the three lumens have different interior dimensions and respectively mate to corresponding differently sized bulkhead fittings on the monitor. This ensures that the filter unit will be installed in the correct orientation with tight interconnections.

[0023] In the preferred embodiment, the body and its lumens are formed by coextrusion of a single piece of plastic material, eg, soft polyvinyl chloride. The consumable filtration medium is then inserted in one of the lumens of the second flow path. A plug is inserted into the distal end of that lumen, which has a flow passageway extending through the plug for receiving a length of the tube segment.

[0024] The piece of tubing is bent into a U-shape to interconnect the two selected lumens. In this regard, the tube segment preferably has an outer diameter that provides an air tight frictional fit when it is inserted in the plug flow passageway and the other lumen of the second flow path. Preferably, the tubing has interior ribs along its length to minimise the likelihood of the tube collapsing or pinching closed when it inserted in the paths. The tube segment is preferably secured to each of the plug flow passageway and the other lumen, which are of about the same inner dimension (diameter), by a conventional solvent dipping and bonding process.

[0025] Advantageously a hydrophobic filter plugs into the distal end of the lumen of the filter unit forming the first flow path. A conventional fitting for receiving the hydrophobic filter is interposed between the canula tubing that is used to take the breath sample from the patient and the filter unit. This construction is particularly advantageous because the filter and fitting elements are quickly and easily assembled by the end user, and alternatively can be provided in a pre-assembled configuration in a clean, but not necessarily sterile package. In addition, it also is extremely low cost because it uses a combination of conventional commercial parts.

[0026] The present invention provides a tool for predicting the likelihood that the determined level of hemolysis will lead to adverse consequences, such as jaundice and hyperbilirubinemia, which might not appear for several days. Thus, the apparatus and methods of the present invention provide for reliable detection and early treatment of the condition by an appropriate remedy, and for monitoring the efficacy of the treatment.

Brief Description of the Drawings

[0027] The present invention will further be described, by way of example with reference to the accompanying drawings, in which like reference characters refer to like parts throughout, and in which:

Figure 1 is a schematic block diagram of an apparatus for determining end-tidal carbon monoxide concentration in accordance with the present invention;

Figure 2 is a diagram of a multipurpose microcontroller board for controlling the device in Figure 1;

Figures 2A - 2D are macro flow diagrams for the overall breath measurements, calibration, and data communication operations of the apparatus of Figure 1.

Figures 2E and 2F are circuit schematic diagrams for a signal conditioning amplifier and a power supply respectively, for interfacing the carbon monoxide sensor of Figure 1 and the microcontroller circuit board of Figure 2;

Figures 3A and 3B are graphical illustrations of measurements of carbon monoxide and carbon dioxide concentrations acquired using the device of Figure 1;

Figures 4A and 4B are graphical illustrations of the carbon monoxide and carbon dioxide concentrations in a representative breath flow;

Figure 5 is an elevated perspective view of a filter unit in accordance with a preferred embodiment of the invention;

Figure 6 is an exploded isometric view of the filter of Figure 5;

Figure 7 is a top cross-sectional view taken along line 7 - 7 of Figure 5;

Figure 8 is an end view taken along line 8 - 8 of Figure 5; and

Figure 9 is a top view of an alternate embodiment of a nasal canula of Figure 1.

Detailed Description of The Invention

[0028] Referring to Fig. 1, a preferred embodiment of the present invention relates to methods and apparatus for monitoring breath flow of a patient over a period of time and determining the end-tidal concentration of carbon monoxide in the breath. The apparatus includes a nasal cannula 10, a carbon dioxide detector 30, an organic vapor filter 45, a flow regulator 50, a pump 60, a carbon monoxide detector 70, and a microcontroller 80. Preferably, a hydrophobic filter 15 is provided between the cannula 10 and the gas detectors to remove moisture from the sample of breath. In particular, filter 15 is used so that moisture does not interfere with detecting carbon dioxide. Filter 15 is illustrated in Fig. 1 as inserted between tube 14a, which includes cannula 10, and a connector 16a, which is secured to the base 5 which supports and preferably encloses the gas detectors 30 and 70, pump 60, and flow regulator 50. One suitable hydrophobic filter 15 is part number 51190, available from Filtertek, Inc.

[0029] Cannula 10 is one segment of tubing 14a which has one end 11 that is adapted for insertion into the nostril (posterior nasal pharynx) of a normally breathing patient, e.g., an infant. End 11 has at least one aperture 12 for extracting a sample of the exhaled breath as described below. Preferably, end 11 has a length and an inner and outer diameter appropriate for insertion into the patient's nostril, e.g., a 3.0 cm length of tubing having an inner diameter on the order of 1.0 to 1.5 mm and an outer diameter of 2-3 mm, and a sufficient number of holes 12 perforating the tube circumference for receiving a sample of breath. The dimensions may be adjusted for the size of the patient. The length of cannula 10 is sufficient to extend from the base 5 to the patient, and is typically on the order of 75 to 100 cm.

[0030] Segments of tubing 14a, 14b, 14c, 14d, 14e, 14f and 14g are used to form the flow path between the various elements of the apparatus as shown in FIG. 1. The tube segments may be made of, for example, medical grade catheter tubing, polyethylene, polypropylene or vinyl. The ends of the segments are typically frictionally fitted over bosses of connectors 16 and the various components as shown in Fig. 1 and may be clamped for a more secure interconnection. Connectors 16a, 16b, and 16c are preferably mounted in the same region of base 5 to allow for easy access for replacement of the cannula and filters.

[0031] Cannula 10 is connected at its other end in series with filter 15, connector 16a, a second length of tubing 14b and the input port 20 of a carbon dioxide detector 30. Detector 30 has a gas sample cell and is used to provide a signal corresponding to the sensed concentration of carbon dioxide in the gas. The detector 30 has a response time that is sufficiently fast to distinguish the concentration level of the end-tidal portion from the other portions of the breath. Thus, the signal changes in response to changes in the concentration of carbon dioxide in the breath as the patient breathes. The resultant signal waveform is used, as described below, to determine the ratio of the end-tidal portion of the breath to the entire inspired air. This ratio, referred to as the duty cycle ("dc") is used to convert the detected carbon monoxide concentration ("CO") to the end-tidal carbon monoxide concentration ("CO_{ET}"), as described below.

[0032] One suitable carbon dioxide gas analyzer is the commercially available Servomex model 1505 fast response carbon dioxide infrared transducer, which is available from Servomex Company, 90 Kerry Place, Norwood, MA 02062.

This device is a temperature compensated, sealed transducer that is based upon a single beam, single wavelength technique absorption for measuring carbon dioxide. It has a complete optical bench and uses a fast infra-red carrier which is attenuated by the infra-red absorption of carbon dioxide in the gas. The device has detection circuitry that will convert fast changes of attenuation into an electrical output signal.

[0033] The Servomex model 1505 transducer is used in accordance with the manufacturers directions and specifications. It provides, under constant conditions, a linear output voltage of from 0 to 1.0 volts corresponding to from 0 to 10% carbon dioxide, and is extendable up to 1.5 volts corresponding to 15% carbon dioxide. The response time is on the order of 120 ms at a flow of 100 ml/min, and the flow rates may be in the range of from 50-200 ml/min. Other carbon dioxide measuring devices also could be used.

[0034] It should be understood that any device that is capable of determining the duty cycle of end-tidal breath to inspired air over a given period of time may be used in place of the carbon dioxide detector, provided that the determined duty cycle is for the same period of time during which the sample on which the carbon monoxide concentration determination is based was acquired. Such a device may be a spirometer for measuring flow velocity or flow volume, a non breath flow device for monitoring breathing, e.g., an impedance pneumograph, a microphone sensor, and the like. Also, a breath gas detector for monitoring a breath gas other than carbon dioxide may be used.

[0035] The carbon dioxide detector is preferred because changes in CO_2 concentrations related to end-tidal flow are relatively large and easily detectable using a threshold level of carbon dioxide. Further, the same sample of breath can be used to determine the carbon monoxide and carbon dioxide concentrations without affecting the sample, particularly when the sample stream is passed through an infrared absorption-type carbon dioxide detector prior to an electrochemical cell type carbon monoxide detector. In addition the use of an exhaled gas (carbon dioxide or another) provides a non intrusive and non invasive technique for determining the duty cycle dc. It does not require an additional or alternate sensor or transducer on or near the patient and it does not require additional patient cooperation or discomfort. Furthermore, using one time-sample of breath to determine the duty cycle of end-tidal breath is more accurate than visually monitoring chest wall movement or respiratory activity over a period of breathing cycles, or relying on a predetermined breathing rate, which are subject to change, and attempting to obtain samples of exhaled breath only during end-tidal portions.

[0036] Other gas sensors may be used, e.g., oxygen which would have a relatively reduced concentration level during end-tidal breath, or hydrogen, which would have a relatively increased concentration level during end-tidal breath. Two different gas detectors, e.g., carbon dioxide and hydrogen, could be used to identify the end-tidal portion, wherein carbon dioxide provides a fast response and hydrogen provides a slow response to changes in concentration.

[0037] Another advantage of the invention with respect to relying on changes in gas concentration levels is that the measurement decouples the breath gas concentrations from rhythmic respiratory activity. In other words, pump 60 may be used to provide a gas flow rate through cannula 10 and the flow path that is greater than the patient's respiratory flow. This, in turn, provides an end-tidal "waveform" stretching that enhances evaluation of the gas concentrations and determination of the end-tidal portion of the breath based on a breath gas. It also provides for synchronization between the respiratory activity corresponding to the end-tidal portion based on carbon dioxide and the detection of carbon monoxide concentration in the same breath sample flow. Consequently, the carbon monoxide concentration may be calculated based on post data acquisition processing analysis of the last acquired sample. As a result, the end-tidal carbon monoxide determination is effectively provided in real-time and without the delay occasioned by the previously reported techniques. In addition, the present invention avoids reliance on a previously established breathing cycle or rate to predict when chest wall movement coincides with end-tidal flow. Instead, the invention is completely responsive to changes in the patient's breathing rate and volume as the sample is acquired. The prior known techniques are not.

[0038] The gas flow output 40 of detector 30 is in turn connected to a piece of tubing 14c and passed through connector 16b into tube segment 14d. Tube segment 14d contains an organic vapor filter 45. Filter 45 may contain any medium that will absorb organic vapors and reducing gases that might interfere with detecting carbon monoxide levels in the carbon monoxide detector 10.

[0039] Filter 45 preferably contains activated charcoal. It is preferably constructed as a canister that either can be inserted interior to the flow path of tube 14d or is inserted between two segments of tubing such that the analyte gas stream passes through the canister. Filter 45 illustrated in Fig. 1 connected between two connectors 16b and 16c so that it is external to base 5. This provides for simple and quick replacement of filter 45 when it is substantially consumed. Filter 45 may be an inexpensive disposable portion of the apparatus.

[0040] One advantage to using filter 45 is that it tends to average the concentrations of gas in the analyte stream by thoroughly mixing the stream within the volume of filter 45. A preferred construction of filter 45 is to use a 20 mm length of charcoal rod having a circumference of 24.4 mm which is sandwiched between 3.0 mm segments of white acetate having the same circumference. The charcoal rod is preferably cut from Filtrona AAD Charcoal Filter Rods, available from American Filtrona Corp., Richmond, Va. Where desired, more than one carbon rod segment may be used, provided that pump 60 has sufficient power to pass the analyte gas stream therethrough.

[0041] Flow regulator 50 and pump 60 are inserted, preferably in tandem as illustrated in Fig. 1, into or between

segments of tubing 14 to maintain a desired constant flow velocity of the analyte stream. Flow regulator 50 is interposed between tubing 14e, which is connected to connector 16c, and tubing 14f, which is connected to pump 60. Pump 60 is in turn interposed between tubing 14f and tubing 14g, which is connected to carbon monoxide detector 70.

[0042] Preferably, pump 60 and flow regulator 50 are adjusted so that the flow is maintained at from 40 to 60 ml/min, more preferably 50 ml/min. This provides for withdrawing continuously a gas sample, either from room air or from the patient's posterior nasal pharynx, depending on placement of the cannula 10, including expired and end-tidal breath for patients having a breathing rate of from 10 to 90 breaths per minute. The flow regulator 50 provides for limiting the flow rate of the analyte gas stream, and the pump 60 provides for sampling the gas sample (room air or breath) such that pump 60 is driven against the flow rate limit set by flow regulator 50. This maintains a constant flow rate for the analyte stream, and avoids any flow surges due to a patient's inhalation or expiration. One suitable flow regulator is orifice/needle valve model F-2822-41-B80-55 available from Air Logic, Racine, Wisconsin, which can be adjusted to obtain the desired gas flow rate in the range of 40-60 ml/min. One suitable pump is model NMP 02 diaphragm micro pump, available from KNF Neuberger, Inc, Princeton, New Jersey, which has a free flow capacity of 0.22 to 0.55 L/min. Pump 60 and flow regulator 50 may be located anywhere in the flow stream, preferably between the carbon dioxide detector 30 and carbon monoxide detector 70 inside the enclosure of base 5. Pump 60 also passes the analyte flow stream out exhaust 75, downstream of the gas detectors 30 and 70 of the apparatus.

[0043] Carbon monoxide detector 70 is preferably an electrochemical sensor that produces an electrical current proportional to the concentration of reducing gases, such as carbon monoxide, which are present in the gas at the gas permeable membrane of detector 70 (not shown). The response time of the carbon monoxide detector 70 and the averaging function of the filter 45 preferably result in a signal output from the detector 70 that is proportional to the average concentration of the reducing gas at the membrane.

[0044] One suitable carbon monoxide sensor is model DragerSensor CO, available from Dragerwerke of Lubeck, Germany. It has a plastic gas permeable membrane, a liquid electrolyte, sensing, reference, and counter electrodes in the electrolyte, and a potentiostatic circuit that maintains a constant voltage between the sensing and reference electrodes. The carbon monoxide in the gas is electrochemically converted at the sensing electrode, which produces a current proportional to the carbon monoxide partial pressure. The device is temperature compensated. It has a concentration sensitivity in the range up to 500 ppm and provides an output current of 0.13± 0.4 µA/ppm, and requires about 20 seconds to equilibrate fully with the gas sample being monitored; it has a reaction half life of ten seconds.

[0045] Microcontroller 80 is used to control the operation of the apparatus. Microcontroller 80 receives signals related to the output signals from carbon dioxide detector 30 and carbon monoxide detector 70, corresponding to the sensed instantaneous carbon dioxide concentration and sensed average carbon monoxide concentration, respectively. These received signals are processed to compute a value corresponding to the end-tidal carbon monoxide concentration in the patient's breath, as described below. The computed value may then be displayed on a display 90, such as a liquid crystal display device.

[0046] Preferably, a conventional digital microcontroller system is used having a suitable software-controlled microprocessor, memory, analog to digital conversion, and signal conditioning functions. Of course, as will be apparent to persons of ordinary skill in the art, discrete analog circuit elements and solid state finite state machines also may be used to control the operation of the elements and obtain the concentration measurement.

[0047] One suitable digital microcontroller is the model Little Giant LG-X miniature microcontroller, available from Z World Engineering, Davis, California. The microcontroller 80 is connected to carbon dioxide detector 30, carbon monoxide detector 70, pump 60, and flow regulator 50 (if one is used) to operate and/or receive signals from those devices. An amplifier interface circuit 82 is used to provide for current to voltage conversion of the signals provided by carbon monoxide detector 70.

[0048] Referring to Fig. 2E, interface circuit 82 includes three amplifiers, U1B, U2B and U3B, which are preferably OP-290 low-noise, dual operational amplifiers available from Precision Monolithics, Inc., Santa Clara, Ca. Amplifier U2B is configured as a current to voltage converter, having a 0.1 µf capacitor C3 in parallel with a 50kΩ resistor R1 in the feedback loop. The gain is determined by resistor R1.

[0049] Amplifier U1B is a second order lowpass filter with approximately a 0.5 second time constant, using two 470kΩ resistors R2 and R3 and two 1µf capacitors C2 and C3 configured as shown. The filter is used to attenuate electrical noise.

[0050] Amplifier U3B is configured as a simple amplifier with gain adjustment potentiometer R8 (100KΩ) in series with a 10kΩ resistor R7, both of which are in parallel with a 0.1 µf capacitor C4 in the feedback loop, and a 10kΩ input resistor R4 at the inverting amplifier input. Potentiometer R8 is used to allow initial calibration to compensate for sensitivity variations in gas detectors. Amplifier U3B also has a secondary input from amplifier U1A, which is configured as an adjustable voltage source that may be used to compensate for a zero gas output of detector 70.

[0051] Amplifier U3A is configured as a unity gain buffer designed to isolate the previous stages from any load effects that may be imposed by following circuitry.

[0052] Amplifier U2A is configured as shown as an adjustable bias source for the counter electrode of detector 70,

as determined by the setting of resistor R21, a 500kΩ potentiometer. A 10kΩ resistor R22 provides a means of reading the bias voltage without making direct contact with the gas detector connections. The CO detector amplifier circuit 82 operates as a low power supply voltage to prevent excess leakage currents from imposing undesirable bias currents on the detector 70, and to allow low power continuous biasing of the detector 70 to allow for stable operation. Preferably, amplifiers U2A and U3A also are type OP-290 amplifiers. In the circuits illustrated in Figs. 2E and 2F, all ground connections are to a virtual ground, which is provided by a CO amplifier power supply circuit 83.

[0053] Referring to Fig. 2F, the CO amplifier power supply and interface circuit 83 is shown. The power supply consists of a normal supply B1 and a backup supply B2. Normal supply B1 may be any nominal +/- 12 volt DC power supply. In one preferred embodiment, normal supply B1 is a regulated power supply derived from AC mains. Alternately, two 12 volt batteries, e.g., rechargeable batteries, could be used.

[0054] Devices Q3 and Q4 are integrated circuit regulators (types LM78L05 and LM79L05) which provide +/-5 volts respectively, for powering the interface amplifier BU1A. Diodes D1 and D2 (IN4148 type diodes) automatically switch to supply to the CO amplifier BU1A the greater of the normal 12 volt DC supply B1a, and the backup battery B2, an alkaline 9 volt battery.

[0055] Device Q1 regulates the supply voltage to +5 volts. Device Q2 is an integrated circuit virtual ground supply, model TLE2425, available from Texas Instruments, Dallas, Texas. Its output "splits" the five volt input into a ± 2.5 volt supply with a virtual ground at 2.5 volts DC "real" potential.

[0056] Amplifier BU1 of circuit 83 includes two type 1458 dual operational amplifiers, BU1A and BU1B, available from National Semiconductor, Santa Clara, CA. Amplifier BU1B is configured as a differential amplifier with gain of 1, and has inputs of the virtual ground from the CO amplifier circuit 82 and the CO amplifier circuit 82 output. Resistors BR3 (120kΩ) and capacitor BC3 (10 µf) provide further low pass filtering with a 1.2 second time constant. Amplifier BU1A is configured as a voltage follower with a low output impedance, for driving the analog input on the Little Giant microcomputer board 80.

[0057] Referring to Fig. 2, the Little Giant LG-X microcontroller 80 is programmable using Z-World's Dynamic C language. It uses about 200 mA, contains a microprocessor Z180 having a 9.216 MHz clock frequency and sufficient memory including read only memory ROM, random access memory RAM, and erasable, programmable read only memory EPROM, which collectively contain the software, data, and memory address locations for operating the apparatus, processing the acquired data, and performing the data manipulation and post acquisition processing functions in accordance with the present invention, as described herein. The device also contains counter-timers, including a 2Hz watchdog timer for automatically resetting the microprocessor in the event of undefined operations or temporary power loss, serial input/output ports, parallel input/output ports, time and date clocks, multichannel analog to digital converter, a digital to analog converter, operational amplifiers for input signal conditioning in single ended or double ended modes, adjustable gain and input voltage ranges, a high current driver output suitable for driving pump 60, and other particular elements provided by the manufacturer which either are used in a conventional manner although not pertinent to the present invention, or are not used. The microcontroller is used in accordance with the manufacturer's directions and specifications, except as otherwise noted, and reference is made to the user manual for the device, entitled "Little Giant Single Board Computer Technical Manual Version E" which is available from the manufacturer, for information regarding configuring and implementing use of the microcontroller.

[0058] The display device 90 is capable of providing a display corresponding to the determined carbon monoxide concentration level in the end-tidal breath CO_{ET}. Preferably, display 90 includes a display screen for alphanumeric text, including the determined CO_{ET} concentration, and preferably instructions to the operator for operating the device to acquire the appropriate gas samples. Further, display device 90 is preferably user-interactive and includes both a keyboard for operator input and a visual display for prompting the operator to act. Also, the display device 90 may include a paper printer or have an associated printer (not shown) for providing a printed copy of the parameters determined and/or measured, in character text or graphic form. Alternately, or in addition, audible sounds, visual indicators or lights may be used to prompt the operator to perform the appropriate act.

[0059] One suitable display device is a model LG-LCD keypad liquid crystal display device, available from Z World Engineering. This device has definable function keys on a keyboard and a visual character display. The visual display includes a 2 line by 16 character LCD. The keyboard has a 4 x 4 keypad and a beeper for keypad feedback. It is compatible with and directly interfaces with the Little Giant LG-X miniature microcontroller.

[0060] Referring to FIG. 2, a printed circuit board layout of the Z World Little Giant microcontroller circuit board is illustrated and the interconnection of elements is described, using the manufacture's conventional pin connections (unless otherwise stated). Referring to terminal board TB1, one or more AC-DC regulated power supplies (not shown) are used to provide the following signals to the four numbered input pins of terminal TB1: -12 volts to pin 1, ground potential to pin 2, +5 volts to pin 3, and +12 volts to pin 4. The corresponding four output pins of terminal board TB1, designated TB1-X' wherein "X" refers to the output pin, are respectively connected in series with the input pins of TB1 and the pins of the apparatus illustrated in Fig. 1 as follows.

[0061] Regarding microcontroller 80, the high current output wiring connectors J1 have pin J1-8 connected to the

negative terminal of pump 60 for providing a current to drive pump 60 at the selected rate. There are no other connections for wiring connectors J1. The power wiring connectors J2 have pin J2-1 connected to J2-4, pin J2-2 connected to J2-3, pin J2-6 connected to TB1-2'(ground), pin J2-7 connected to TB1-4'(+12v), and no other J2 pin being connected. The RS485 field wiring connectors J3 are not used in this embodiment.

[0062] The analog input field wiring connectors J4 have pins J4-1 and J4-2 connected to amplifier interface board pins J2-1 and J2-2 respectively, pin J4-3 connected to pin PL4-1 on the Servomex 1505 board, and pin J4-4 connected to pin PL4-2 on the Servomex model 1505 board. Analog input pins J5, RS232 port pins J7, and RS485 program pins J9 are not used. The pins at keyboard interface J6 are used to connect a flat ribbon cable to the back panel of the display 90, LCD display device model LG-LCD. The pins J8 for the RS232 port are connected on the back panel to a conventional nine pin D-sub connector. The display 90 interface pins J10 are connected as follows. Pin J10-10 are the common front panel buttons; pin J10-12 is for button #1, pin J10-14 is for button #2, pin J10-16 is for button #3, and pin J10-18 is for button #4.

[0063] Regarding the Servomex model 1505 circuit board, it is connected as follows. For device Power, pin PL1-1 is connected to TB1" (-12v), pin PL1-2 is not connected, pin PL1-3 is connected to TB1-2' (ground), pin PL1-4 is connected to TB1-3' (+5v). For device Thermistor Status, pins PL2 are not connected. For device Nitrous Oxide Compensation, pins PL3-1 and PL3-2 are jumpered and no other pins are connected. For device Signal Output, pins PL4-1 is connected to Little Giant pin J4-3 and pin PL4-2 is connected to Little Giant board J4-4. For device Remote Calibration Adjustment, there are no pin connections.

[0064] Referring now to Figs. 5-9, in a preferred embodiment of the invention, the segment of tubing between hydrophobic filter 15 and fitting 16a, and the tubing segment between fittings 16b and 16c (the segments illustrated as 14d in Fig. 1) are formed as part of a disposable filter unit 500. Filter unit 500 is preferably constructed as a single housing having three lumens 502, 504, and 506 and a tube segment 508 that is used to connect together lumens 504 and 506 as described in more detail below. Filter unit 500 is preferably made of a soft polyvinyl chloride (PVC), more preferably, a single extruded body having the three lumens that is made of soft PVC. The outer surface of filter unit 500 may have a ribbed surface, for example, longitudinal ribs for a distinctive appearance, horizontal ribs to improve gripping, or both. Preferably, the three lumens are extruded with their longitudinal axes lying in a common plane and with different inner diameters, as illustrated in Fig. 8.

[0065] In alternate constructions, filter unit 500 may be formed of three separate extrusions that are glued or otherwise secured together, and the three lumens may be spaced with their respective axes offset vertically and/or horizontally within filter unit 500.

[0066] Filter unit 500 has a unit facing end 501, a distal end 503, a plug 510, a cap 512, and filter 45. Filter 45 is inserted into cap 512 and together they are passed into the interior of lumen 504. Filter 45 comprises a length of activated carbon filter 45a and two lengths of cellulose acetate 45b, one on either side of carbon 45a. Carbon 45a may be, for example, a length of activated carbon filter cut from a commercial product known as #R-15243, available from American Filtrona Corp., Richmond Virginia USA, which has a circumference of about 24.7 mm. Cellulose acetate 46b may be conventional cellulose acetate, such as is used in the manufacture of smoking cigarettes. Carbon filter 45a may have a length of 20 mm. Each piece of cellulose acetate 46b may have a length of 5 mm and a circumference of 24.7 mm.

[0067] Cap 512 is a cylindrical receptacle made of a material having a low coefficient of friction with respect to the interior wall of lumen 504, e.g., a polyethylene material. It is used to insert filter 45 into lumen 504 without damaging the structural integrity of filter 45 and to form a press fit compressive seal between cap 512, filter 45, and the inside walls of lumen 504. Cap 512 is provided with a thickness on the order of 0.75 mm, and retains filter 45 without distorting its shape. Cap 512 has an open end 513 opening toward the distal end 503 that is about the same diameter as filter 45 for receiving the components of filter 45. Cap 512 also has an aperture 515 facing end 501 that is about the same diameter as the inner or outer diameter of lumen 506. The latter diameter is not critical, except that the end of cap 512 having aperture 515 retain filter 45 as the assembly is inserted into lumen 504 and provide a flow path through filter 45 with an acceptable pressure drop. In this regard, cap 512 is sealingly interposed between filter and lumen 504 so that the analyte flow stream through lumen 504 will pass through filter 45 and inside cap 512 and not around filter 45 or cap 512.

[0068] Filter 45 is preferably assembled as a sandwich of acetate 46b, carbon 45a, and acetate 46b, such that at least one acetate section 46b and carbon 46a is inserted into cap 512. The assembled cap 512 and filter 45 is then press-fit inserted into lumen 504 to an appropriate depth. Preferably, filter 45 is finally located to be centered about the midpoint of lumen 504. It is important that an organic lubricant not be used to insert cap 512 into lumen 504. Water may be used as a lubricant, if necessary.

[0069] Plug 510 is a cylindrical plug made of PVC that is inserted into lumen 504 on the end 503 side of filter 45. Plug 510 has a length d21 of about 1.0 cm and an air flow passageway 511 extending through its longitudinal axis, having an inner diameter of about 0.3 cm. The length is not critical but must be sufficient to retain tube segment 508. Plug 510 may be secured into lumen 50 by dipping it in a solvent and inserting the dipped part into lumen 504 from

end 503 so that they bond together. In a preferred embodiment, when fully seated, cap 512 is spaced from the inner end of plug 510 by a distance d11 of about 0.3 cm. This provides for full access to the entire cross-sectional area of filter 45 by the analyte flow stream.

[0070] Tube segment 508 is preferably a length of vinyl tube having longitudinally extending ribs along the inner surface (not shown). The ribs prevent tube 508 from pinching off after it is bent and secured in place in unit 500. In this regard, the ends of tube segment 508 are dipped in solvent and then inserted into lumen 506 and the inner passageway 511 of plug 510 to a depth sufficient to retain tube 508 securely. A suitable depth is about 1.0 cm. Accordingly, tube 508 may have an overall length of about 6 cm. an outer diameter of about 0.3 cm., and an inner diameter of about 0.15 cm. Alternately, tube 508 may be frictionally fit into lumen 506 and passageway 511.

[0071] In a preferred embodiment, lumen 502 has an inner diameter of about 0.15 cm., lumen 504 has an inner diameter of about 0.83 cm., and lumen 506 has an inner diameter of about 0.3 cm., connector 16a has a maximum outer diameter d1 of about 0.19 cm., connector 16b has a maximum outer diameter d2 of about 0.87 cm., and connector 16c has a maximum outer diameter d3 of about 0.34 cm. The thickness of each lumen wall may be on the order of 0.15 cm., such that there is about a double thickness between adjacent lumens in the midplane of unit 500, as illustrated in Fig. 7. By using these dimensions, which are exemplary and not critical, the different lumen diameters may be frictionally fit securely only onto the correspondingly sized bulkhead connectors 16a, 16b, and 16c (see Fig. 7). This assures that filter unit 500 will be correctly connected to monitor 5. Alternate spacing or orientation of the three lumens and the corresponding bulkhead connectors could be used to accomplish the same function. Also, the bulkhead connectors could be recessed so that filter 500 is supported by both the recess and the connectors.

[0072] Referring to Figs. 6 and 9, a preferred embodiment of the invention employs obtaining a gas sample using canula 10, a fitting 605, and hydrophobic filter 15. Fitting 605 is preferably a male tapered luer with an integral locking ring and a barb 606 for a 1/16" (.159 cm.) inner diameter tube. It is designed to pass into lumen 502 of filter unit 500 and remain securely connected by a frictional fit. Fitting 605 may be made of nylon, preferably a white nylon. One such suitable fitting is part no. MTLL210-1, available from Value Plastics, Inc., Fort Collins, Colorado, USA.

[0073] Filter 15 may be a part No. 3.0 mm. filter F1#57120, available from Filtertek, Hebron, Illinois, USA, which screws directly into the patient side of fitting 605.

[0074] Canula 10 is preferably a length of plastic tube such as an infant feeding tube with a distal tip that has been modified to provide an insertion mark 601 and two apertures 602 and 603, all located within a distance d31 of about one centimeter of end 11. End 11 is preferably open. Canula 10 also has a tapered receptacle 610 which is configured to mate securely with a tapered protrusion 15' (See Fig. 6) of filter 15 in a conventional manner.

[0075] Insertion mark 601 provides a depth gauge for the user to insert end 11 into the patient's nostril, e.g., until insertion mark 601 enters the nostril. Apertures 602 and 603 are spaced equidistantly between mark 601 and end 11 and located on opposite sides of the tubing. Apertures 602 and 603 extend only through one side of tube 10. More or different apertures and different aperture locations also may be used. One suitable tube is model No. 1219-15 5FRx36" feeding tube, available from Medovations, Inc. Milwaukee, Wisconsin, USA, which is customized as noted, and which mates directly to the tapered protrusion of filter 15.

[0076] Preferably, canula 10 is separately packed in a sterile package which is opened immediately prior to use. In this regard, filter 15 and fitting 605 may be provided together with canula 10 in sterile packaging, separate from canula 10 and filter unit 500 in clean packaging, or together with filter unit 500 (and optionally completely or partially preassembled therewith) in clean packaging. If desired, the complete canula 10, filter 15 and filter unit 500 could be preassembled and packed in sterile packaging.

[0077] According to a preferred embodiment of the present invention, the end-tidal carbon monoxide concentration of the patient is measured in the following manner. An initial value of carbon monoxide may be obtained for analysis purposes. Pump 60 is then started and a sample of room air is drawn through monitor 5 at the selected flow rate of, e.g., 50 ml/min, past the carbon dioxide detector 30 and the carbon monoxide detector 70. At the end of a first time period, e.g., 45 seconds, the measures of the concentrations of the carbon dioxide and carbon monoxide in the sample cells of the carbon dioxide sensor 30 and carbon monoxide sensor 70 are obtained, respectively. The measures are obtained as analog signals from the detectors 70 and 30, e.g., sensed currents converted to conditioned voltages v_{CO} and v_{CO2}, which are respectively digitized into n-bit words (n is preferably 8) at selected sampling rates and passed into a data buffer and/or memory. The values are stored as CO_{room} and CO_{2zero}.

[0078] Pump 60 is then turned off and the cannula 10 is placed in the patient's nostril, preferably in the posterior nasal pharynx. Then the pump 60 is turned on again and an analyte stream of breath is drawn past the respective gas detectors 70 and 30. The concentrations of carbon monoxide and carbon dioxide are respectively sensed and sampled during a second time period, e.g., 45 seconds.

[0079] The acquired measures of the carbon dioxide concentration over the second time period are evaluated. First, the relative changes in the carbon dioxide concentration are evaluated to determine the duty cycle corresponding to the end-tidal portion of the patient's breath. An average of the end-tidal CO_2 concentration ("CO_{2ET}") to the average CO_2 is obtained, providing the duty cycle dc.

[0080] The end tidal CO concentration ("CO_{ET}") is then determined from the following relationship:

$$CO_{ET} = [CO_{mean} - CO_{room}] / dc \quad (1)$$

where CO_{mean} is the average or mean carbon monoxide concentration at the end of the second period, and dc is the duty cycle determined for CO_{2ET}.

[0081] Referring to FIG. 1, the macro flow diagrams of FIGS. 2A to 2D, a preferred embodiment of the operation of the present invention is now described. In this embodiment, display device 90 is configured to use four buttons which are used for controlling the operation of the apparatus. Button #1 is a start button to initiate some action by the apparatus to reset the apparatus operation, button #2 is a reset button, button #3 is a select button to select some option from a menu, and button #4 is a menu button to display one or more instruction and/or operation menu. Each button is activated by pressing in and then releasing the button. Other alternatives for providing user input in an interactive device may, of course, be used.

[0082] Referring to FIG. 2A, the device becomes activated on power on or reset (pressing button #2) and enters an initialization sequence at step 100. During initialization, the operating code of microcontroller 80 is booted and various system checks and device initializations are performed. Following initialization, the routine passes to an idle state at step 110, where it waits for user input. During the idle state, the system preferably generates a suitable message on display 90, e.g., "Ready, press 1 to start". Thus, during the idle step 110, the user may provide an input by pressing button #1 to start a measuring sequence. This passes the operating routine to step 120.

[0083] Also during the idle state 110, the operator may press button #3 to select a sequence from a menu displayed on the display unit 90, and button #4 to display various operation sequences. One such sequence is a calibration routine for calibrating the carbon monoxide detector 70 and carbon dioxide detector 30 at step 130. The operator also may press button #2 at any time to exit whatever routine it is executing, reset the apparatus, and return the routine to step 100.

[0084] Referring to FIGS. 2A and 2B, in response to pressing button #1 in the idle state 110, the routine moves from the idle step 110 to step 120 for the sequence for determining end-tidal carbon monoxide concentration CO_{ET}. There are three phases to this determination, a sequence at step 121 for measuring the background carbon monoxide CO_{room} during a first time period, a pause or delay period at step 122, and a sequence at step 123 for measuring breath carbon dioxide CO_2 and carbon monoxide CO during a second time period.

[0085] In the present invention, before each sample is obtained, pump 60 is off for a delay time period. This allows the CO detector to return to a zero state so that effectively no CO is in the sample cell. When desired, a supply of inert gas may be provided and pump 60 activated for a time to clear the sample cell of any CO (and CO_2) gas. A three-way valve and an actuator may be included (not shown) to achieve this cell clearing function. The delay time period is at least about one minute, more preferably three minutes.

[0086] In the background measurement sequence step 121, the user is prompted to place the end 11 of cannula 10 somewhere in the vicinity of the patient, but not inside the nostril and then to press button #1. In response to pressing button #1, pump 60 is activated at time t_0 and the background room air is drawn through tubing 14 and during a first time period of approximately 45 seconds. During this time, display 90 preferably displays a suitable message corresponding to the duration of the background measuring test, e.g., how much time remains to complete the test, in seconds or in percent.

[0087] At time t_1 at the end of the first time period, pump 60 is turned off. The carbon monoxide concentration in the sample cell of the carbon monoxide detector 70 is then determined and recorded in memory as CO_{room}. As noted, the carbon monoxide gas detector has a time response to the analyte flow that produces an average carbon monoxide concentration. The digitized samples corresponding to the carbon monoxide concentration are then processed so that the output signal is the average of the last five acquired samples. Preferably the determined concentration value is displayed, e.g., in parts per million (ppm). The amplitude of the voltage signal v_{CO}, corresponding to the averaged sensed carbon monoxide concentration CO_{room} from detector 70 that is displayed, also may be displayed for diagnostic purposes.

[0088] The CO and CO_2 gas equations used to convert the sampled voltage signals corresponding to the detector signal outputs to gas concentrations are:

$$CO\ ppm = m_1 v_{CO} + c_1 \quad (2)$$

$$CO_2\ \% = m_2 v_{CO2} + c_2, \quad (3)$$

where m_1 and c_1 are the slope and intercept calibration constants relating the voltage v_{CO} derived from the CO detector 70 output in response to the concentration of carbon monoxide in a sample to ppm, and m_2 and c_2 are the slope and intercept calibration constants relating the voltage v_{CO2} derived from the CO_2 detector 30 output in response to the carbon dioxide concentration in a sample, in percent.

[0089] Thus, at time t_0, with CO = 0 ppm, using the above equation:

$$0 = m_1 v_{CO} + c_1 \text{ and} \tag{2.1}$$

$$c_1 = -m_1 v_{CO\text{-}0} \tag{2.2}$$

where $v_{CO\text{-}O}$ corresponds to the signal produced by CO detector 70 at time t_o. At time t_1,

$$CO_{room} \text{ ppm} = m_1 v_{CO\text{-}1} + c_1. \tag{2.3}$$

$$= m_1 v_{CO\text{-}1} - m_1 v_{CO\text{-}0} \tag{2.4}$$

$$= m_1 (v_{CO\text{-}1} - v_{CO\text{-}0}) \tag{2.5}$$

where $v_{CO\text{-}1}$ corresponds to the signal produced by CO detector 70 at time t_1.

[0090] When pump 60 is stopped at time t_1 at the conclusion of the background step 121, the CO is measured and the routine enters pause step 122. During the pause step 122, the operator is prompted to place the nasal cannula 10 inside the patient's nostril and then to press button #1 to resume the measurement sequence. The system preferably displays a suitable message on display 90, e.g., "place nasal cannula", to prompt the user to place the cannula 10. The pause step 122 preferably includes a minimum delay period Timeout of about ten seconds and a maximum delay period Timeout of about five minutes. Thus, if the operator does not press the start button #1 within the Timeout period, the system will return to the idle state 110. The Timeout period is used to provide for sampling the room air and patient carbon monoxide concentrations within a time period wherein it is not likely that the room air concentration level will change very much. The Timeout period also is selected to permit the operator sufficient time to insert the nasal cannula 10 in a patient, such as a newborn infant, which may require some time to accomplish.

[0091] Once the cannula 10 is place, the operator presses button #1 to resume the measurement sequence 123. At time t_2, pump 60 is turned on for a second time period, which is preferably the same as the first time period, i.e., 45 seconds. Initial CO and CO_2 samples may be obtained for analytical purposes. During this second time period, the display 90 preferably displays a suitable message corresponding to the duration of the measuring test, e.g., how much time remains to complete the test, in seconds or in percent. At time t_3, at the end of the second time period, pump 60 is turned off.

[0092] During the second time period, the signals corresponding to the CO_2 concentration obtained from CO_2 detector 30 are acquired. The relative changes in CO_2 concentration over time are then used to calculate the duty cycle dc of the patient's end-tidal breath. Preferably, the signal corresponding to the carbon dioxide concentration is periodically sampled, e.g., the analog signal is digitized at a first sampling rate, e.g., 30 Hz during the second time period. These samples are stored in a data buffer for post data acquisition processing and analysis.

[0093] Also, the signals corresponding to the CO concentrations obtained from detector 70 are acquired during the second time period. Preferably, the carbon monoxide concentration is periodically sampled, e.g., the analog signal is digitized at a sampling rate of 1.0 Hz during the second time period. These samples also are stored in the data buffer for analysis.

[0094] FIGS. 3a and 3b illustrate representative sampled waveforms of the signals v_{CO} and V_{CO2} provided by the CO and CO_2 detectors 70 and 30 respectively, during a second time period. The waveforms thus display the concentration levels sensed corresponding to the calibrated CO and CO_2 levels. In these representative drawings, the calibration functions were:

$$CO \text{ ppm} = 12.11 V_{CO} + 0.95;$$

and

$$CO_2\ \% = 11.96\ V_{CO2} + 0.$$

The calculated duty cycle dc was 42.30%, the CO_{ET} was 2.10 ppm, the CO_{ROOM} was 2.01 ppm, the V_{CO-O} was -0.78 v and the v_{CO-1} was 0.088 v. The v_{CO} min was -0.05 v and the v_{CO} max was 0.17 v (corresponding also to the start (t2) and stop (t3) measurement voltages). The maximum v_{CO2} was about .42 volts.

[0095] The 30 Hz sampling rate of CO_2 was selected because it corresponds to the anatomical waveform of respiration from which the ratio of the end-tidal portion total air can be derived. The CO_2 sensor time response of 120 ms gives adequate resolution without acquiring excessive data. The sampling rate of 1 Hz for the CO detector voltage V_{CO} was selected because the CO detector has a much slower response time (the half time of the CO response is about ten seconds) which cannot discriminate the end-tidal portions and room air. Sampling at a higher rate would not significantly improve the data resolution. The selected rates were selected as compromises between collecting sufficient data with adequate resolution in view of the sensor response time, and may be changed according to the sensors used and the particular conditions of use.

[0096] Following acquisition of the data, the data is processed by the microprocessor Z180 of microcontroller 80 to derive the duty cycle and the end-tidal CO concentration CO_{ET}. The digitized samples of the voltage v_{CO} are passed through a low pass digital filter, which may be implemented by suitable software, which takes an average of the last five samples. This filter is used to suppress noise. It also advantageously permits use of the output of the digital filter without further averaging or storage of separate values. The corresponding average or mean CO concentration at time t_3, CO_{mean}, is thus

$$CO_{mean} = m_1\ V_m + c_1. \tag{4}$$

where V_m is the average of the last five voltage samples v_{CO}.

[0097] The duty cycle dc is calculated based on analysis of the sampled voltages v_{CO2} between time t_2 and t_3, as follows:

$$dc = \frac{[\text{the number of } CO_2 \text{ samples} > V_t]}{[\text{total number of } CO_2 \text{ samples}]}$$

$$= \frac{[\text{the number of } CO_2 \text{ samples} > 1.5\%]}{[\text{total number of } CO_2 \text{ samples}]}$$

where V_t is a selected threshold voltage corresponding to, e.g., a 1.5 % CO_2 concentration, and is obtained from the CO_2 gas equation (3) as follows:

$$1.5\% = m_2\ V_t + c_2,$$

$$V_t = (1.5 - c_2)/m_2.$$

For an ideal CO_2 detector 70, $m_2 = 10$ and $c_2 = 0$, such that $V_t = 0.15$ volts. Of course, other values and threshold voltages could be used as appropriate in the particular circumstances.

[0098] Then, the patient's end-tidal CO concentration CO_{ET} is:

$$CO_{ET} = (CO_{mean} - CO_{room})/dc. \tag{1}$$

This may be calculated in a straightforward manner from the acquired data.

[0099] The foregoing equations are based on the realization that the physical behavior of CO and CO_2 are very similar with respect to, for example, diffusion, flow rates and other behavior characteristics in the patient's cardiopulmonary system. Accordingly, it can be assumed that ratio of the end-tidal CO_2 to the total CO_2 is the same as the ratio of the end-tidal CO to the total CO. This is illustrated in FIGS. 4a and 4B. Further, it can be assumed that the CO_2 concentration of room air is approximately 0 and that the end-tidal CO_2 concentration is related to the duty cycle of the

breath waveform and the mean value of the CO_2 concentration, namely:

$$CO_{2ET} * dc = CO_{2mean}. \quad (5)$$

Thus, based on these assumptions, the CO and CO_2 ratios are

$$\frac{CO_{2ET} - CO_{2room}}{CO_{2mean} - CO_{2room}} = \frac{CO_{2mean}/dc - 0}{CO_{2mean} - 0} = \frac{CO_{ET} - CO_{room}}{CO_{mean} - CO_{room}}$$

and thus

$$1/dc = \frac{CO_{et} - CO_{room}}{CO_{mean} - CO_{room}} \quad (6)$$

and the total end-tidal CO_{ET} is

$$CO_{ET} = \frac{(CO_{mean} - CO_{room})}{dc} + CO_{room} \quad (7)$$

Therefore, to obtain the patient's actual end-tidal CO level produced, the portion of the patient's breath from the CO_{room} concentration (i.e., the CO level that was inhaled by the patient) must be subtracted from the total, which yields the equation (1) above.

[0100] The determined values are then displayed on display 90 and any desired printouts of the acquired data may be made or stored to a memory device or medium for subsequent analysis, as desired. The routine then exits the measuring sequence 120 and returns to the idle state at 110. The display preferably include the determined CO_{ET}, e. g., in ppm, and also may provide the duty cycle of the carbon dioxide waveform corresponding to the end-tidal portion, and/or various voltages from the detectors 30 and 70, such as minimum and maximum voltages corresponding to CO and CO_2, and initial and final voltages for CO_{mean} and/or CO_2 during the second time period. It is noted that, in connection with the second time period for monitoring the patient's breathing, the time references t_0 and t_1 may be used in place of time references t_2 and t_3 respectively.

[0101] Preferably, the data from the measurement cycle just finished will remain displayed for a period of time to allow the operator to record manually the data. The display 90 may be cleared by pressing button #1 (or reset #2). Following measurement of a sample, the aforementioned delay time period of about one minute (or three minutes) is provided to allow the CO and CO_2 detectors 70 and 30 to decay to a "zero" state before the next background measurement cycle begins. Preferably, any attempt to obtain another measurement before the end of the delay period will be simply delayed until the expiration of that time, and then automatically commence.

[0102] Referring to FIGS. 2A and 2C, the CO and CO2 detectors 70 and 30 are periodically calibrated using conventional CO and CO_2 gases having known concentrations. To begin the calibration sequence 130, the system must be in the idle state 110. The operator then presses button #4 to call the menu up on display 90. The menu will display an appropriate message such as "menu 1. Calibrate CO/CO2 sensor. Activate button #1 to start". The operator then presses button #1 which begins the calibration sequence 130. The calibration sequence involves the selection of test gases of known concentrations, inputting the known concentration values into the system during set-up sequence 131 for CO and set-up sequence 133 for CO_2, operating the pump 60 to draw the known gas into the system and determining the signal level produced by the detector (30 or 70 depending on the gas; only one detector is calibrated at a time) in response to the known gas concentration during measurement sequence 132 for CO and measurement sequence 134 for CO_2.

[0103] In a preferred embodiment, the display 90 is used to provide a sequence of instructions for the operator to input data, such as which gas detector is to be calibrated and the concentration of the test gas that is to be used (sequences 131 and 133). This is followed by providing a sample of that test gas, which is then sampled and measured (sequences 132 and 134). Preferably, at least two gas samples at different known concentrations are used for each of CO and CO_2. From these two samples, the foregoing gas calibration equations (2) and (3) for converting a provided voltage to a gas concentration are determined. The calibration equations are reasonably accurate over the concentration ranges of interest, e.g., accurate within 10%.

[0104] In one embodiment, in sequences 131 and 133, a keyboard associated with display 90 may be used to input the test gas type and concentration data directly by pressing alphanumeric characters. In accordance with a preferred embodiment using the Little Giant LCD display device, select button #3 is used to toggle a digit that is underscored on the display screen menu between values, to display the known gas concentration value. The menu button #4 is used to move the underscore along the displayed characters for selecting the character to be changed. Start button #1 is used to indicate that the character now displayed is the correct value, which value is then stored for use in deriving the calibration function for the gas detector being calibrated. The calibration is thus conducted in a known manner and preferably produces a linearized calibration function.

[0105] Preferably two samples of each gas at known concentrations are used. Thus, two points are obtained, (v1, p1) and (v2, p2), where v1 and v2 are the measured voltages and p1 and p2 are the corresponding known gas concentrations. Using these two test points, the calibration constants are conventionally obtained as follows:

$$m = (p2-p1)/(v2-v1) \tag{8}$$

$$c = (p1\ v1 - p2\ v1)/(v2-v1). \tag{9}$$

[0106] Referring to FIG. 2D, a macro flow diagram of the data communication function of the apparatus is shown. Initialization step 100 provides for initialization of the communications channel. This channel establishes serial RS-232 communication under the industry standard x-modem protocol with external devices, such as portable computers. It is used to monitor the operation of the gas analyzer and for development and diagnosis of system failures. Any terminal device such as a portable computer equipped with a suitable communication program such as BITCOM, or PROCOMM, will automatically be able to receive the data files at 9600 baud for the examination and evaluation.

[0107] The foregoing routines may be implemented in software for controlling the described elements in a conventional manner that is within the abilities of a person of ordinary skill in the art. Implementation of the present invention in alternate microprocessor controlled devices, analog circuit controlled devices, and finite state machines with appropriate controlling software, integrated and/or discrete circuit elements and logic circuits, is believed to be within the ability of a person of ordinary skill in the art.

[0108] One advantage of the present invention that it provides a simple and easy-to-use device that accurately and relatively quickly obtains a measure of the end-tidal carbon monoxide concentration of a patient. The determination is made immediately following acquisition of the breath sample and is thus performed in real-time. It overcomes the abovenoted problems of the prior art techniques. Another advantage of the invention is that it provides a reusable apparatus with a disposable canula and a disposable filter unit containing a consumable organic filtration medium. This facilitates quick and easy replacement of parts requiring replacement due to the end of their useful life while maintaining the durable measuring apparatus intact. The disposable filter unit is particularly advantageous because it incorporates conventional materials processing which can be performed in high volume production runs at low cost, and uses simple, inexpensive assembly procedures, rather than more complicated fabrication techniques, to obtain very low-cost units. Similarly, the use of off-the-shelf fittings and hydrophobic filters provides additional cost savings over proprietary products. The present invention is particularly useful for detecting abnormal levels of hemolysis in newborn and premature infants, as well as determining incipient hyperbilirubinemia, elevated levels of bilirubin, the likelihood of the onset of jaundice, and the resolution of those conditions over time. Importantly, with respect to newborn and premature newborns, it provides for enhanced detection of potential problems before the new-borns are discharged from the hospital.

Claims

1. Apparatus (5) for monitoring a patient's end-tidal gas flow during breathing characterised by:

   a first gas detector (70) for monitoring the concentration of a first selected gas in a gas sample and having an output corresponding to the monitored first selected gas concentration;

   a first monitoring and determining means (30, 80) for monitoring the patient's breathing and determining the ratio of the patient's end-tidal breath portion to inspired air as a duty cycle and having an output corresponding to the determined duty cycle;

   first providing means (10, 80) for providing a sample of room air to the first gas detector (70) for measuring a

background concentration of the first gas;

second providing means (10, 80) for providing a sample of the patient's breath to the first gas detector for measuring a breath sample concentration of the first gas in the patient's breath; and

first receiving and determining means (80) for receiving the output of the first gas detector and the first monitoring means and being arranged to determine the end-tidal concentration of the first gas in response to the determined duty cycle, the determined background concentration of the first gas in room air, and the determined breath sample concentration of the first gas in the patient's breath.

2. The apparatus of claim 1 characterised in the first gas is carbon monoxide, the first gas detector (70) is arranged to detect the concentration of carbon monoxide, and the first receiving and determining means determines the end-tidal concentration of carbon monoxide.

3. The apparatus of claim 1 or 2 wherein the first monitoring and determining means is further characterised by:

a second gas detector (30) for monitoring the concentration of a second selected gas in the patient's breath other then the first selected gas and having an output corresponding to the second selected gas concentration; and

second receiving and determining means (80) for receiving the output of the second gas detector and for determining the duty cycle as the ratio of the end-tidal portion of the second gas in the patient's breath to the patient's breath based on monitored relative changes in the sensed concentration of the second gas.

4. The apparatus of claim 3 characterised in that the second gas detector (30) is a carbon dioxide gas analyser.

5. The apparatus of claims 3 or 4 wherein the second providing means (10) is further characterised by a flow path connecting the first and second gas detectors (30, 70) in gaseous communication and a pump (60) for passing a gas sample therethrough wherein the second gas detector (30) monitors changes in the concentration of the second gas in the patient's breath over time.

6. The apparatus of claim 5 characterised in that the first providing means (80) is arranged to turn the pump (60) on for a first selected time period, preferably 45 seconds, and the first gas detector (30) detects the room air concentration of the first gas, and the second providing means (80) is arranged to turn the pump (60) on for a second selected first time period, preferably 45 seconds, following the end of a first time period.

7. The apparatus of any of claims 3 - 6 wherein the second receiving and determining means is further characterised by:

first means (80) for periodically sampling the output of the second gas detector (30) corresponding to the sensed concentration of the second gas during the first selected time period; and

a comparator for comparing the sampled signals to a selected threshold;

and in which the second receiving and determining means determines the duty cycle based on the sampled signals that are above and below the selected threshold, preferably based on the number of sampled signals above the selected threshold and the number of samples.

8. The apparatus of any of claims 1 - 7 further characterised by:

second means (80) for periodically sampling the output of the first gas detector corresponding to the sensed concentration of the first gas during the first selected time period; and

means (80) for providing a first signal corresponding to an average of a selected number of sampled second signals near the end of the first period.

9. The apparatus of any of claims 3, 5, 6, 7, 8 and 9 characterised in that the first gas detector (70) is a carbon monoxide gas analyser and the second gas detector (30) is a carbon dioxide gas analyser.

10. The apparatus of claims 2 or 9 characterised in that the first gas detector (70) detects the room air carbon monoxide concentration in response to the first providing means (80) and an average concentration of carbon monoxide in the patient's breath in response to the second providing means (80) and the first receiving and determining means determines the end-tidal carbon monoxide concentration based on the room air concentration, the average concentration and the duty cycle.

11. The apparatus of claim 1 characterised in that the first means for monitoring breathing further comprises a sensor for coupling to the patient for sensing changes in the patient's respiratory activity, such as an impedance pneumograph sensor or spirometer.

12. The apparatus of claim 4 characterised in that:

the carbon monoxide gas analyser (20) has a gas input for receiving a gas sample (11) and a signal output (CO) representative of the measured concentration of carbon monoxide in the gas sample, said carbon monoxide gas analyser having a response time that is not sufficiently fast to distinguish the carbon monoxide concentration of the end-tidal portion from other portions of a gas sample that is a patient breath flow;

the carbon dioxide gas analyser has an input for receiving a gas sample (11) and a signal output (C02) representative of the measured concentration of carbon dioxide in the gas sample, said carbon dioxide gas analyser having a response time that is sufficiently fast to distinguish the carbon dioxide concentration of the end-tidal portion from other portions of a gas sample that is a patient breath flow;

the second receiving and determining means has a means (80) for analysing the signal output (CO2) over a given time period and determining a duty cycle for said signal output relative to a reselected signal parameter; and in which

the first providing means (10, 80) is arranged to provide a room air gas sample flow to the carbon monoxide gas analyser for a first duration so that the carbon monoxide gas analyser signal output (CO) corresponds to a background carbon monoxide concentration;

the second means (10, 80) is arranged to provide a patient breath flow gas sample flow of a second duration to the carbon monoxide gas analyser and to the carbon dioxide gas analyser, wherein the carbon monoxide gas analyser signal output (CO) corresponds to an average carbon monoxide concentration near the end of the second duration, the preselected signal parameter corresponds to the patient's end-tidal carbon dioxide concentration, and the analysing means (80) determine the duty cycle of the end-tidal portion of the breath flow sample; and

the receiving and determining means (80) receives the background carbon monoxide concentration, the average carbon monoxide concentration and the determined duty cycle and is arranged to calculate therefrom the end-tidal carbon monoxide concentration.

13. The apparatus of claim 12 wherein the first and second providing means are further characterised by:

a flow path (14) connecting the gas inputs of the carbon monoxide and carbon dioxide gas analysers, the flow path having a gas inlet (20) for receiving a gas sample (11);

a pump (60) connected to the flow path; and

a switch (80) for operating the pump to cause the gas sample at the gas inlet to flow along the flow path to the carbon monoxide and carbon dioxide gas analysers.

14. The apparatus of any of claims 12 - 13 characterised in that the calculating means (80) is arranged to calculate the end-tidal carbon monoxide concentration as equal to the quantity of the average carbon monoxide concentration minus the background carbon monoxide concentration divided by the duty cycle, wherein the duty cycle corresponds to the end-tidal portion of the patient breath flow gas sample.

15. A method of measuring end-tidal carbon monoxide concentration in expired breath characterised by the steps of:

(a) measuring the carbon monoxide concentration in ambient room air (CO_{room});

(b) sampling the patient's breath over a first period of time;

(c) measuring the carbon monoxide concentration (CO) in the sample patient's breath during the first time period;

(d) determine the duty cycle of the end-tidal portion of the patient's breath during the first time period; and

(e) determining the end-tidal carbon monoxide level based on the determined duty cycle, the measured ambient concentration of carbon monoxide (CO_{room}), and the measured carbon monoxide concentration in the patients breath during the time period (CO).

16. The method of claim 15 characterised in that step (e) is further characterised by subtracting the measure CO_{room}, from the measured CO and dividing the difference by the determined duty cycle.

17. The method of claim 15 characterised in that step (a) is further characterised by passing a stream of room air through a carbon monoxide detector during a second time period and measuring the CO_{room} corresponding to the room carbon monoxide concentration, preferably as an average of the CO concentration.

18. The method of claims 15 - 17 characterised in that step (d) is further characterised by determining the duty cycle based on the sample breath during the first time period.

19. The method of claim 18 characterised in that step (d) is further characterised by:

(i) detecting the end-tidal portion of a second gas in the sample breath other than the first gas; and

(ii) determining the duty cycle as the ratio of the end-tidal portion to the sample breath portion of the second gas during the first time period.

20. The method of claim 19 characterised in that the second gas is carbon dioxide.

21. The method of claims 19 or 20 characterised in that step (e) is further characterised by subtracting the measured CO_{room} from the measured CO and dividing the difference by the determined cycle.

Patentansprüche

1. Vorrichtung (5) zur Überwachung des endexspiratorischen Gasflusses eines Patienten während der Atmung, gekennzeichnet durch:

- einen ersten Gasdetektor (70) zur Überwachung der Konzentration eines ersten gewählten Gases in einer Gasprobe, dessen Ausgangssignal der Konzentration des ersten gewählten überwachten Gases entspricht;
- ein erstes Überwachungs- und Bestimmungsmittel (30, 80) zur Überwachung der Atmung des Patienten und zur Bestimmung des Verhältnisses des endexspiratorischen Anteils des Patientenatems zur eingeatmeten Luft als Endphase, dessen Ausgangssignal der ermittelten Endphase entspricht;
- erste Zuführungsmittel (10, 80) zur Zuführung einer Probe der Raumluft zum ersten Gasdetektor (70) zur Messung der Untergrundkonzentration des ersten Gases;
- zweite Zuführungsmittel (10, 80) zur Zuführung einer Probe des Patientenatems zum ersten Gasdetektor zur Messung der Konzentration des ersten Gases in der Atemprobe des Patienten;
- erste Empfangs- und Bestimmungsmittel (80) zum Empfang des Ausgangssignals vom ersten Gasdetektor und vom ersten Überwachungsmittel, eingerichtet zur Bestimmung der endexspiratorischen Konzentration des ersten Gases in Abhängigkeit von der ermittelten Endphase, der bestimmten Untergrundkonzentration des ersten Gases in der Raumluft und der bestimmten Konzentration des ersten Gases in der Atemprobe des Patienten.

2. Vorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß das erste Gas Kohlenmonoxid ist, der erste Gasdetektor für den Nachweis der Kohlenmonoxidkonzentration eingerichtet ist und das erste Empfangs- und Bestim-

mungsmittel die end-exspiratorische Konzentration des Kohlenmonoxids bestimmt.

3. Vorrichtung nach Anspruch 1 oder 2, wobei das erste Empfangs- und Bestimmungsmittel außerdem gekennzeichnet ist durch

   - einen zweiten Gasdetektor (30) zur Überwachung der Konzentration eines zweiten gewählten, vom ersten gewählten Gas verschiedenen Gases im Patientenatem, dessen Ausgangssignal der Konzentration des zweiten gewählten Gases entspricht; und
   - zweite Empfangs- und Bestimmungsmittel (80) zum Empfang des Ausgangssignals vom zweiten Gasdetektor und zur Ermittlung der Endphase als Verhältnis des endexspiratorischen Anteils des zweiten Gases im Patientenatem zum Patientenatem auf der Grundlage der festgestellten relativen Änderungen der gemessenen Konzentration des zweiten Gases.

4. Vorrichtung nach Anspruch 3, dadurch gekennzeichnet, daß der zweite Gasdetektor (30) eine Gasmeßzelle für Kohlendioxid ist.

5. Vorrichtung nach Anspruch 3 oder 4, wobei das zweite Zuführungsmittel (10) außerdem gekennzeichnet ist durch einen Fließweg, der den ersten und den zweiten Gasdetektor (30, 70) gasführend verbindet, und durch eine Pumpe (60) zum Durchleiten einer Gasprobe durch diese, wobei der zweite Gasdetektor (30) Änderungen der Konzentration des zweiten Gases im Patientenatem mit der Zeit überwacht.

6. Vorrichtung nach Anspruch 5, dadurch gekennzeichnet, daß das erste Zuführungsmittel (80) zum Einschalten der Pumpe (60) für eine erste gewählte Zeitspanne, vorzugsweise 45 s, eingerichtet ist und der erste Gasdetektor (30) die Konzentration des ersten Gases in der Raumluft mißt, und daß das zweite Zuführungsmittel (80) zum Einschalten der Pumpe (60) für eine zweite gewählte Zeitspanne, vorzugsweise 45 s, die auf das Ende der ersten Zeitspanne folgt, eingerichtet ist.

7. Vorrichtung nach einem der Ansprüche 3 bis 6, wobei das zweite Empfangs- und Bestimmungsmittel außerdem gekennzeichnet ist durch:

   - erste Mittel (80) zum periodischen Abtasten des Ausgangssignals des zweiten Gasdetektors (30) entsprechend der gemessenen Konzentration des zweiten Gases während der ersten gewählten Zeitspanne; und
   - einen Komparator zum Vergleich der Probesignale mit einem gewählten Schwellenwert;
   - und worin das zweite Empfangs- und Bestimmungsmittel die Endphase auf der Grundlage der abgetasteten Signale über und unter dem gewählten Schwellenwert ermittelt, vorzugsweise auf der Grundlage der Anzahl der abgetasteten Signale über dem gewählten Schwellenwert und der Anzahl der Abtastwerte.

8. Vorrichtung nach einem der Ansprüche 1 bis 7, außerdem gekennzeichnet durch:

   - zweite Mittel (80) zur periodischen Abtastung des Ausgangssignals des ersten Gasdetektors entsprechend der gemessenen Konzentration des ersten Gases während der ersten gewählten Zeitspanne; und
   - Mittel (80), die ein erstes Signal entsprechend einem Mittelwert einer gewählten Anzahl von zweiten Abtastwerten gegen das Ende der ersten Zeitspanne liefern.

9. Vorrichtung nach einem der Ansprüche 3, 5, 6, 7, 8 und 9, dadurch gekennzeichnet, daß der erste Gasdetektor (70) eine Gasmeßzelle für Kohlenmonoxid und der zweite Gasdetektor (30) eine Gasmeßzelle für Kohlendioxid ist.

10. Vorrichtung nach Anspruch 2 oder 9, dadurch gekennzeichnet, daß der erste Gasdetektor (70) die Konzentration des Kohlenmonoxids in der Raumluft aus dem ersten Zuführungsmittel (80) und die mittlere Kohlenmonoxidkonzentration im Patientenatem aus dem zweiten Zuführungsmittel mißt und daß das erste Empfangs- und Bestimmungsmittel die endexspiratorische Kohlenmonoxidkonzentration auf der Grundlage der Konzentration in der Raumluft, der mittleren Konzentration und der Endphase bestimmt.

11. Vorrichtung nach Anspruch 1, dadurch gekennzeichnet, daß das erste Mittel zur Überwachung der Atmung außerdem einen an den Patienten anschließbaren Sensor zur Erfassung von Änderungen der Atmungsaktivität des Patienten, wie einen Impedanzpneumographensensor oder ein Spirometer, umfaßt.

12. Vorrichtung nach Anspruch 4, dadurch gekennzeichnet, daß

- die Kohlenmonoxid-Gasmeßzelle (20) einen Gaseinlaß zur Aufnahme einer Gasprobe (11) und ein der in der Gasprobe gemessenen Kohlenmonoxidkonzentration entsprechendes Ausgangssignal (CO) aufweist, wobei diese Kohlenmonoxid-Gasmeßzelle eine Ansprechzeit hat, die nicht hinreichend kurz ist, um die Kohlenmonoxidkonzentration im endexspiratorischen Anteil von anderen Anteilen in der Gasprobe des Atemstroms des Patienten unterscheiden zu können;
- die Kohlendioxid-Gasmeßzelle einen Einlaß zur Aufnahme einer Gasprobe (11) und ein der in der Gasprobe gemessenen Kohlendioxidkonzentration entsprechendes Ausgangssignal (CO_2) aufweist, wobei diese Kohlendioxid-Gasmeßzelle eine Ansprechzeit hat, die hinreichend kurz ist, um die Kohlendioxidkonzentration im endexspiratorischen Anteil von anderen Anteilen in der Gasprobe des Atemstroms des Patienten unterscheiden zu können;
- das zweite Empfangs- und Bestimmungsmittel ein Mittel (80) zur Analyse des Ausgangssignals (CO_2) über eine gegebene Zeitdauer und zur Bestimmung der Endphase für dieses Ausgangssignal in Bezug zu einem vorgewählten Signalwert aufweist, und wobei
- das erste Zuführungsmittel (10, 80) für die Lieferung eines Gasprobenstroms aus der Raumluft zur Kohlenmonoxid-Gasmeßzelle über eine erste Zeitdauer eingerichtet ist, so daß das Ausgangssignal (CO) der Kohlenmonoxid-Gasmeßzelle der Untergrundkonzentration an Kohlenmonoxid entspricht;
- das zweite Mittel (10, 80) für die Lieferung eines Gasprobenstroms aus dem Patientenatem zur Kohlenmonoxid-Gasmeßzelle und zur Kohlendioxid-Gasmeßzelle über eine zweite Zeitdauer eingerichtet ist, wobei das Ausgangssignal (CO) der Kohlenmonoxid-Gasmeßzelle der mittleren Kohlenmonoxidkonzentration gegen Ende der zweiten Zeitdauer entspricht, der vorgewählte Signalwert der endexspiratorischen Kohlendioxidkonzentration des Patienten entspricht und die Analysemittel (80) die Endphase des endexspiratorischen Anteils der Atemflußprobe ermitteln; und
- das Empfangs- und Bestimmungsmittel (80) die Untergrundkonzentration an Kohlenmonoxid, die mittlere Kohlenmonoxidkonzentration und die ermittelte Endphase empfängt und für die Berechnung der endexspiratorischen Kohlenmonoxidkonzentration aus diesen eingerichtet ist.

13. Vorrichtung nach Anspruch 12, wobei das erste und zweite Zuführungsmittel außerdem gekennzeichnet ist durch:

- einen die Gaseinlässe der Kohlenmonoxid- und der Kohlendioxid-Gasmeßzelle verbindenden Fließweg (14), der einen Gaseinlaß (20) zur Aufnahme einer Gasprobe (11) aufweist;
- eine mit dem Fließweg verbundenen Pumpe (60); und
- einen Schalter (80) zur Betätigung der Pumpe, um die Gasprobe am Gaseinlaß zum Fließen längs des Fließpfades zur Kohlenmonoxid- und Kohlendioxid-Gasmeßzelle zu veranlassen.

14. Vorrichtung nach einem der Ansprüche 12 bis 13, dadurch gekennzeichnet, daß das Berechnungsmittel (80) die end-exspiratorische Kohlenmonoxidkonzentration als gleich der mittleren Kohlenmonoxidkonzentration minus Untergrundkonzentration an Kohlenmonoxid dividiert durch die Endphase berechnen kann, wobei die Endphase dem endexspiratorischen Anteil der Gasstromprobe aus dem Patientenatem entspricht.

15. Verfahren zur Messung der endexspiratorischen Kohlenmonoxidkonzentration in ausgeatmeter Atemluft, gekennzeichnet durch die Schritte:

a) Messung der Kohlenmonoxidkonzentration in der umgebenden Raumluft (CO_{room});
b) Probenahme des Patientenatems über eine erste Zeitspanne;
c) Messung der Kohlenmonoxidkonzentration (CO) in der Atemprobe des Patienten während der ersten Zeitspanne;
d) Ermittlung der Endphase des endexspiratorischen Anteils des Patientenatems während der ersten Zeitspanne;
e) Bestimmung des endexspiratorischen Kohlenmonoxidpegels aus der ermittelten Endphase, der gemessenen Umgebungskonzentration des Kohlenmonoxids (CO_{room}) und der während der Zeitspanne gemessenen Kohlenmonoxidkonzentration (CO) im Patientenatem.

16. Verfahren nach Anspruch 15, dadurch gekennzeichnet, daß der Schritt e) außerdem gekennzeichnet ist durch Subtraktion des gemessenen CO_{room} vom gemessenen CO und Division der Differenz durch die ermittelte Endphase.

17. Verfahren nach Anspruch 15, dadurch gekennzeichnet, daß der Schritt a) außerdem gekennzeichnet ist durch Hindurchleiten eines Stroms Raumluft durch einen Kohlenmonoxiddetektor während einer zweiten Zeitspanne und

Messung von CO_{room} entsprechend der Kohlenmonoxidkonzentration im Raum, vorzugsweise als Mittelwert der CO-Konzentration.

18. Verfahren nach Anspruch 15 bis 17, dadurch gekennzeichnet, daß der Schritt d) außerdem gekennzeichnet ist durch Bestimmung der Endphase aus der Atemprobe während der ersten Zeitspanne.

19. Verfahren nach Anspruch 15 bis 17, dadurch gekennzeichnet, daß der Schritt d) außerdem gekennzeichnet ist durch

    i) Feststellung des endexspiratorischen Anteils eines vom ersten verschiedenen zweiten Gases in der Atemprobe; und
    ii) Bestimmung der Endphase als Verhältnis des endexspiratorischen Anteils zum Atemprobeanteil des zweiten Gases während der ersten Zeitspanne.

20. Verfahren nach Anspruch 19, dadurch gekennzeichnet, daß das zweite Gas Kohlendioxid ist.

21. Verfahren nach Anspruch 19 oder 20, dadurch gekennzeichnet, daß der Schritt e) außerdem gekennzeichnet ist durch Subtraktion des gemessenen CO_{room} vom gemessenen CO und Division der Differenz durch die ermittelte Endphase.

Revendications

1. Appareil (5) pour mesurer l'écoulement de gaz en fin d'expiration d'un patient pendant la respiration caractérisé par :

    - un premier détecteur de gaz (70) pour mesurer la concentration d'une premier gaz choisi dans un échantillon de gaz et ayant une sortie correspondant à la concentration mesurée du premier gaz choisi ;
    - des premiers moyens de mesure et de détermination (30, 80) pour mesurer la respiration du patient et déterminer le rapport de la partie de souffle en fin d'expiration du patient sur l'air inspiré comme cycle utile et ayant une sortie correspondant au cycle utile déterminé ;
    - des premiers moyens d'approvisionnement (10, 80) pour fournir un échantillon d'air de la pièce au premier détecteur de gaz (70) pour mesurer une concentration de bruit de fond du premier gaz ;
    - des seconds moyens d'approvisionnement (10, 80) pour fournir un échantillon du souffle du patient au premier détecteur de gaz pour mesurer une concentration d'échantillon de souffle du premier gaz dans le souffle du patient ; et
    - des premiers moyens de réception et de détermination (80) pour recevoir la sortie du premier détecteur de gaz et du premier moyen de mesure, disposés pour déterminer la concentration en fin d'expiration du premier gaz en réponse au cycle utile déterminé, la concentration déterminée de bruit de fond du premier gaz dans l'air de la pièce, et la concentration déterminée de l'échantillon de souffle du premier gaz dans le souffle du patient.

2. Appareil selon la revendication 1,
caractérisé en ce que
le premier gaz est du monoxyde de carbone, le premier détecteur de gaz (70) est arrangé pour détecter la concentration du monoxyde de carbone, et le premier moyen de réception et de détermination détermine la concentration du monoxyde de carbone en fin d'expiration.

3. Appareil selon la revendication 1 ou 2,
caractérisé en ce que
le premier moyen pour mesurer et déterminer est encore caractérisé par :

    - un second détecteur de gaz (30) pour mesurer la concentration d'un second gaz choisi dans le souffle du patient autre que le premier gaz choisi et ayant une sortie correspondant à la seconde concentration de gaz choisi ; et
    - un second moyen de réception et de détermination (80) pour recevoir la sortie du second détecteur de gaz et pour déterminer le cycle utile comme le rapport de la partie en fin d'expiration du second gaz dans le souffle du patient sur le souffle du patient basé sur des changements mesurés relatifs de la concentration détectée

du second gaz.

4. Appareil selon la revendication 3,
caractérisé en ce que
le second détecteur de gaz (30) est un analyseur de gaz dioxyde de carbone.

5. Appareil selon les revendications 3 ou 4,
caractérisé en ce que
le second moyen d'approvisionnement (10) est caractérisé en plus par une voie d'écoulement reliée aux premier et second détecteurs de gaz (30, 70) dans une liaison gazeuse et une pompe (60) pour faire passer un échantillon de gaz à travers dans laquelle le second détecteur de gaz (30) mesure les changements de la concentration du second gaz dans le souffle du patient au cours du temps.

6. Appareil selon la revendication 5,
caractérisé en ce que
le premier moyen d'approvisionnement (80) est arrangé pour mettre en marche la pompe (60) sur une première période de temps choisie, de préférence 45 secondes, et le premier détecteur de gaz (30) détecte la concentration de l'air de la pièce du premier gaz, et le second moyen d'approvisionnement (80) est arrangé pour mettre en marche la pompe (60) pour une deuxième période de temps choisie, de préférence 45 secondes, après la fin de la première période.

7. Appareil selon l'une quelconques des revendications 3 à 6,
caractérisé en ce que
le second moyen de réception et de détermination est en plus caractérisé par :

- un premier moyen (80) pour périodiquement prélever la sortie du second détecteur de gaz (30) correspondant à la concentration détectée du second gaz au cours de la première période de temps ; et
- un comparateur pour comparer les signaux prélevés à un seuil choisi, et
- dans lequel le second moyen de réception et de détermination détermine le cycle utile basé sur les signaux prélevés qui sont au-dessus et en-dessous du seuil choisi, de préférence basé sur le nombre des signaux prélevés au-dessus du seuil choisi et le nombre d'échantillons.

8. Appareil selon l'une quelconque des revendications 1 à 7,
caractérisé en plus par :

- un second moyen (80) pour périodiquement prélever la sortie du premier détecteur de gaz correspondant à la concentration détectée du premier gaz au cours de la première période de temps choisie ; et
- un moyen (80) pour fournir un premier signal correspondant à une moyenne d'un nombre choisi de deuxièmes signaux prélevés proches de la fin de la première période.

9. Appareil selon l'une quelconque des revendications 3, 5, 6, 7, 8, 9,
caractérisé en ce que
le premier détecteur de gaz (70) est un analyseur de monoxyde de carbone et le second détecteur de gaz (30) est un analyseur de dioxyde de carbone.

10. Appareil selon les revendications 2 ou 9,
caractérisé en ce que
le premier détecteur de gaz (70) détecte la concentration de monoxyde de carbone de l'air de la pièce en réponse au premier moyen d'approvisionnement (80), et une concentration moyenne de monoxyde de carbone dans le souffle du patient en réponse au second moyen d'approvisionnement (80), et le premier moyen de réception et de détermination détermine la concentration en monoxyde de carbone en fin d'expiration basée sur la concentration de l'air de la pièce, la concentration moyenne et le cycle utile.

11. Appareil selon la revendication 1,
caractérisé en ce que
le premier moyen pour mesurer la respiration comprend de plus un capteur pour coupler au patient des changements détectés dans l'activité respiratoire du patient, tels qu'un capteur pneumographe à impédance ou un spiromètre.

12. Appareil selon la revendication 4, caractérisé en ce que

- l'analyseur de gaz de monoxyde de carbone (20) a une entrée de gaz pour recevoir un échantillon de gaz (11) et une sortie de signal (CO) représentative de la concentration mesurée de monoxyde de carbone dans l'échantillon de gaz, cet analyseur de gaz de monoxyde de carbone ayant un temps de réponse qui n'est pas suffisamment rapide pour distinguer la concentration en monoxyde de carbone de la partie en fin d'expiration des autres parties d'un échantillon de gaz qui est un écoulement de souffle du patient ;
- l'analyseur de gaz de dioxyde de carbone a une entrée pour recevoir un échantillon de gaz (11) et une sortie de signal (C02) représentative de la concentration mesurée de dioxyde de carbone dans l'échantillon de gaz, cet analyseur de gaz de dioxyde de carbone ayant un temps de réponse qui est suffisamment rapide pour distinguer la concentration en dioxyde de carbone de la partie en fin d'expiration des autres parties d'un échantillon de gaz qui est un écoulement de souffle du patient ;
- le deuxième moyen de réception et de détermination a un moyen (80) pour analyser la sortie de signal (C02) pendant une période de temps donnée et déterminer un cycle utile pour cette sortie de signal relativement à un paramètre du signal pré-sélectionné ; et dans lequel
- le premier moyen d'approvisionnement (10, 80) est arrangé pour fournir un écoulement d'échantillon de gaz d'air de la pièce à l'analyseur de gaz de monoxyde de carbone pour une première durée de sorte que la sortie du signal d'analyseur de gaz de monoxyde de carbone (CO) corresponde à une concentration en monoxyde de carbone de bruit de fond ;
- le deuxième moyen (10, 80) est arrangé pour fournir un écoulement d'échantillon de gaz de l'écoulement du souffle du patient d'une deuxième durée à l'analyseur de gaz de monoxyde de carbone et à l'analyseur de gaz de dioxyde de carbone, dans lequel la sortie de signal de l'analyseur de gaz de monoxyde de carbone (CO) correspond à une concentration moyenne en monoxyde de carbone proche de la fin de la deuxième durée, le paramètre du signal pré-sélectionné correspond à la concentration en dioxyde de carbone en fin d'expiration du patient, et les moyens d'analyse (80) déterminent le cycle utile de la partie en fin d'expiration de l'échantillon d'écoulement du souffle ; et
- le moyen de réception et de détermination (80) reçoit la concentration en monoxyde de carbone de bruit de fond, la concentration moyenne en monoxyde de carbone et le cycle utile déterminé et est chargé de calculer à partir de cela la concentration en monoxyde de carbone en fin d'expiration.

13. Appareil selon la revendication 12, caractérisé en ce que les premiers et deuxièmes moyens d'approvisionnement sont encore caractérisés par :

- une voie d'écoulement (14) reliant les entrées de gaz des analyseurs de gaz de monoxyde de carbone et de dioxyde de carbone, la voie d'écoulement ayant une admission de gaz (20) pour recevoir un échantillon de gaz (11) ;
- une pompe (60) reliée à la voie d'écoulement ; et
- un commutateur (80) pour actionner la pompe pour faire que l'échantillon de gaz à l'admission de gaz s écoule le long de la voie d'écoulement vers les analyseurs de gaz de monoxyde de carbone et de dioxyde de carbone.

14. Appareil selon l'une quelconque des revendications 12 à 13, caractérisé en ce que le moyen calculateur (80) est arrangé pour calculer la concentration en monoxyde de carbone en fin d'expiration comme égale à la quantité de la concentration moyenne en monoxyde de carbone moins la concentration en monoxyde de carbone de bruit de fond divisée par le cycle utile, le cycle utile correspondant à la partie en fin d'expiration de l'échantillon de gaz de l'écoulement du souffle du patient.

15. Méthode pour mesurer la concentration en monoxyde de carbone en fin d'expiration dans le souffle expiré caractérisé par les étapes consistant à :

(a) mesurer la concentration en monoxyde de carbone dans l'air ambiant de la pièce ($CO_{pièce}$) ;
(b) prélever le souffle du patient pendant une première période de temps ;
(c) mesurer la concentration en monoxyde de carbone (CO) dans le souffle d'échantillon du patient pendant la première période de temps ;
(d) déterminer le cycle utile de la partie en fin d'expiration du souffle du patient pendant la première période de temps ; et

(e) déterminer le niveau de monoxyde de carbone en fin d'expiration basé sur le cycle utile déterminé, la concentration ambiante mesurée en monoxyde de carbone ($CO_{pièce}$), et la concentration mesurée en monoxyde de carbone dans le souffle des patients pendant la période de temps (CO).

16. Méthode selon la revendication 15,
caractérisée en ce que
l'étape (e) est encore caractérisée en soustrayant la mesure $CO_{pièce}$, de la CO mesurée et en divisant la différence par le cycle utile déterminé.

17. Méthode selon la revendication 15,
caractérisée en ce que
l'étape (a) est encore caractérisée en passant un flux d'air de la pièce par un détecteur de monoxyde de carbone pendant une deuxième période de temps et en mesurant la $CO_{pièce}$ correspondant à la concentration en monoxyde de carbone de la pièce, de préférence comme une moyenne de la concentration de CO.

18. Méthode selon les revendications 15 à 17,
caractérisée en ce que
l'étape (d) est encore caractérisée en déterminant le cycle utile basé sur le souffle de l'échantillon pendant la première période de temps.

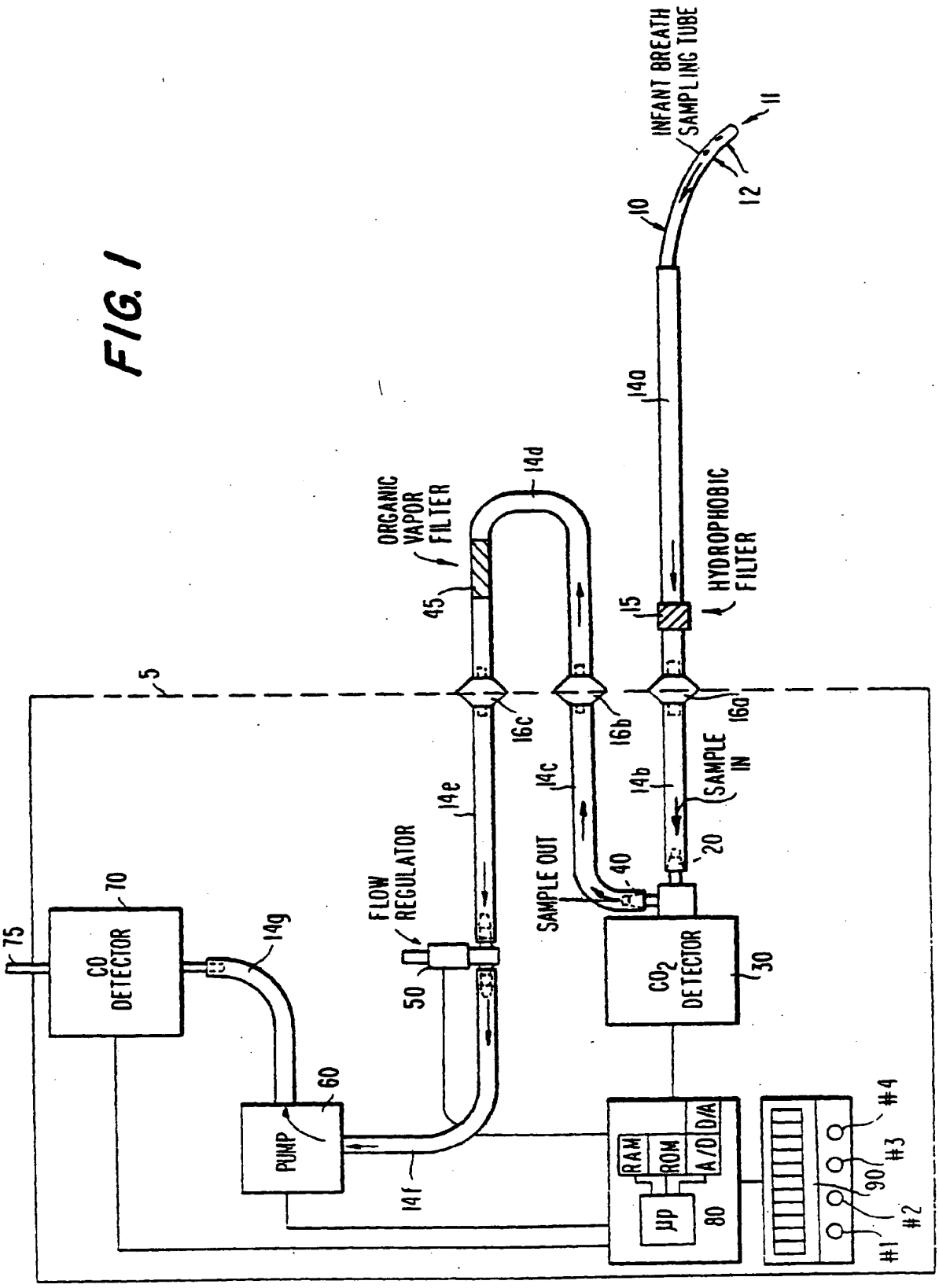
19. Méthode selon la revendication 18,
caractérisée en ce que
l'étape (d) est encore caractérisée par :

(i) détecter la partie de fin d'expiration d'un deuxième gaz dans le souffle de l'échantillon autre que le premier gaz ; et
(ii) déterminer le cycle utile comme rapport de la partie de fin d'expiration à la partie de souffle de l'échantillon du deuxième gaz pendant la première période de temps.

20. Méthode selon la revendication 19,
caractérisée en ce que
le deuxième gaz est le dioxyde de carbone.

21. Méthode selon les revendications 19 ou 20,
caractérisée en ce que
l'étape (e) est encore caractérisée en soustrayant le CO-pièce mesuré par la CO mesurée et en divisant la différence par le cycle déterminé.

FIG. 1


INFANT BREATH SAMPLING TUBE
11
12
10
14a
HYDROPHOBIC FILTER
15
ORGANIC VAPOR FILTER
45
14d
5
16c
16b
16a
SAMPLE IN
14b
14c
SAMPLE OUT
40
20
14e
FLOW REGULATOR
50
CO DETECTOR
70
75
14g
CO2 DETECTOR
30
PUMP
60
14f
RAM
ROM
A/D
D/A
μP
80
#1
#2
#3
#4
90

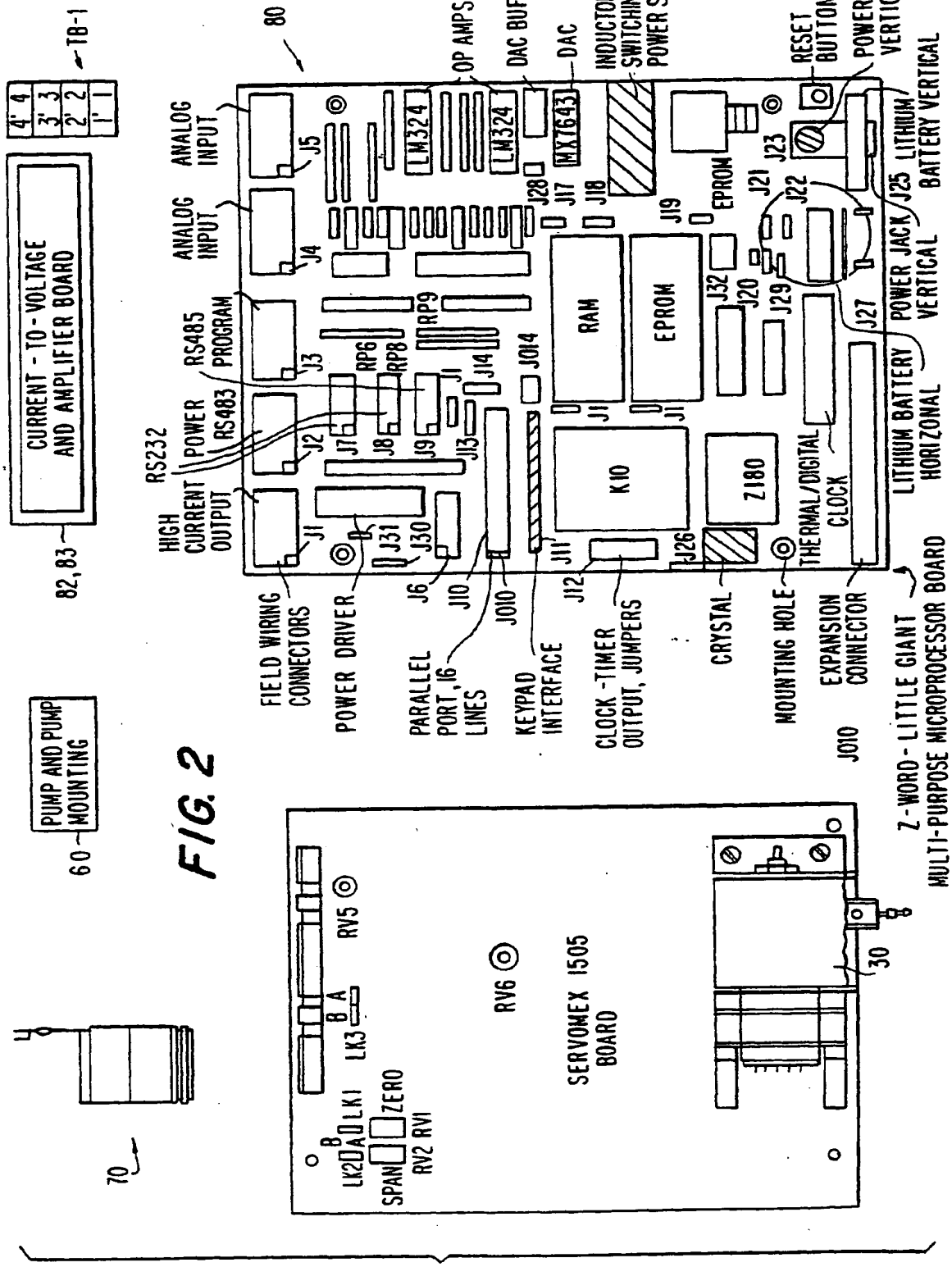

TB-1
4' 4
3' 3
2' 2
1' 1
CURRENT - TO - VOLTAGE AND AMPLIFIER BOARD
82, 83
80
ANALOG INPUT
J5
ANALOG INPUT
J4
OP AMPS
LM324
DAC BUFFER
LM324
DAC
MX7643
INDUCTOR SWITCHING POWER SUPPLY
RESET BUTTON
POWER JACK VERTICAL
LITHIUM BATTERY VERTICAL
J23
J21
J22
J25
J28
J17
J18
J19
EPROM
RS485 PROGRAM
J3
RS232
POWER RS483
J2
RP6
RP8
RP9
J1
J14
J014
J7
J8
J9
J3
RAM
EPROM
J32
J20
J29
J27
POWER JACK VERTICAL
LITHIUM BATTERY HORIZONAL
HIGH CURRENT OUTPUT
J1
J31
J30
J6
J10
J010
J11
J12
J26
K10
Z180
THERMAL/DIGITAL CLOCK
FIELD WIRING CONNECTORS
POWER DRIVER
PARALLEL PORT, 16 LINES
KEYPAD INTERFACE
CLOCK - TIMER OUTPUT, JUMPERS
CRYSTAL
MOUNTING HOLE
EXPANSION CONNECTOR
J010
Z - WORD - LITTLE GIANT MULTI - PURPOSE MICROPROCESSOR BOARD
PUMP AND PUMP MOUNTING
60
70
SERVOMEX 1505 BOARD
RV5
RV6
B A
LK3
LK1
LK2
B
A
ZERO
SPAN
RV2 RV1
30

FIG. 2

FIG. 2A

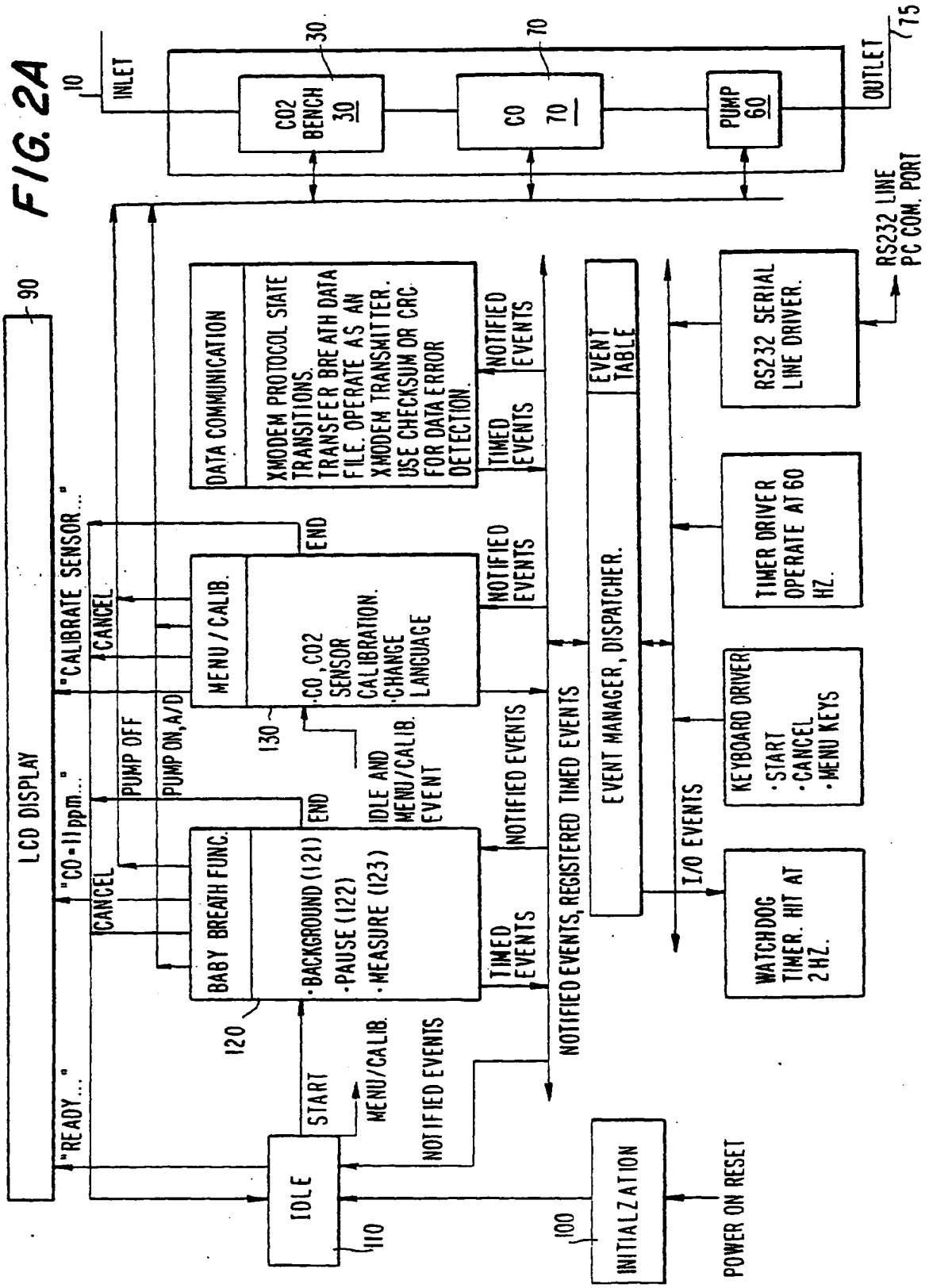

INLET
10
CO2 BENCH 30
30
CO 70
70
PUMP 60
OUTLET
75
RS232 LINE PC COM. PORT
RS232 SERIAL LINE DRIVER.
LCD DISPLAY
90
"READY..."
"CO=11ppm..."
"CALIBRATE SENSOR..."
CANCEL
PUMP OFF
PUMP ON, A/D
DATA COMMUNICATION
XMODEM PROTOCOL STATE TRANSITIONS. TRANSFER BREATH DATA FILE. OPERATE AS AN XMODEM TRANSMITTER. USE CHECKSUM OR CRC FOR DATA ERROR DETECTION.
MENU / CALIB.
END
·CO, CO2 SENSOR CALIBRATION. ·CHANGE LANGUAGE
130
IDLE AND MENU/CALIB. EVENT
BABY BREATH FUNC.
·BACKGROUND (121) ·PAUSE (122) ·MEASURE (123)
120
NOTIFIED EVENTS
TIMED EVENTS
NOTIFIED EVENTS, REGISTERED TIMED EVENTS
EVENT MANAGER, DISPATCHER.
EVENT TABLE
I/O EVENTS
TIMER DRIVER OPERATE AT 60 HZ.
KEYBOARD DRIVER ·START ·CANCEL ·MENU KEYS
WATCHDOG TIMER. HIT AT 2 HZ.
IDLE
110
START
MENU/CALIB.
INITIALZATION
100
POWER ON RESET

FIG. 2B

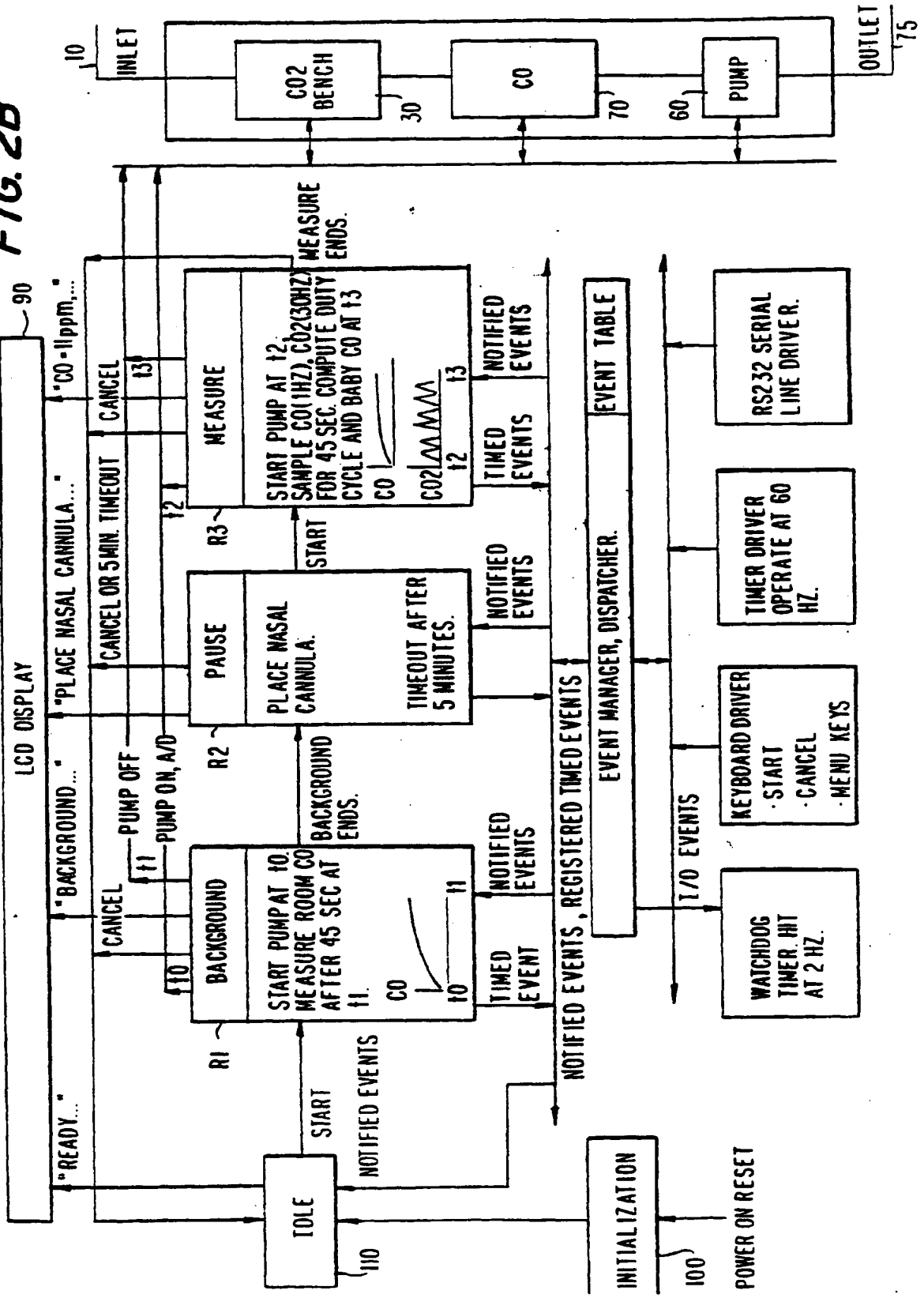
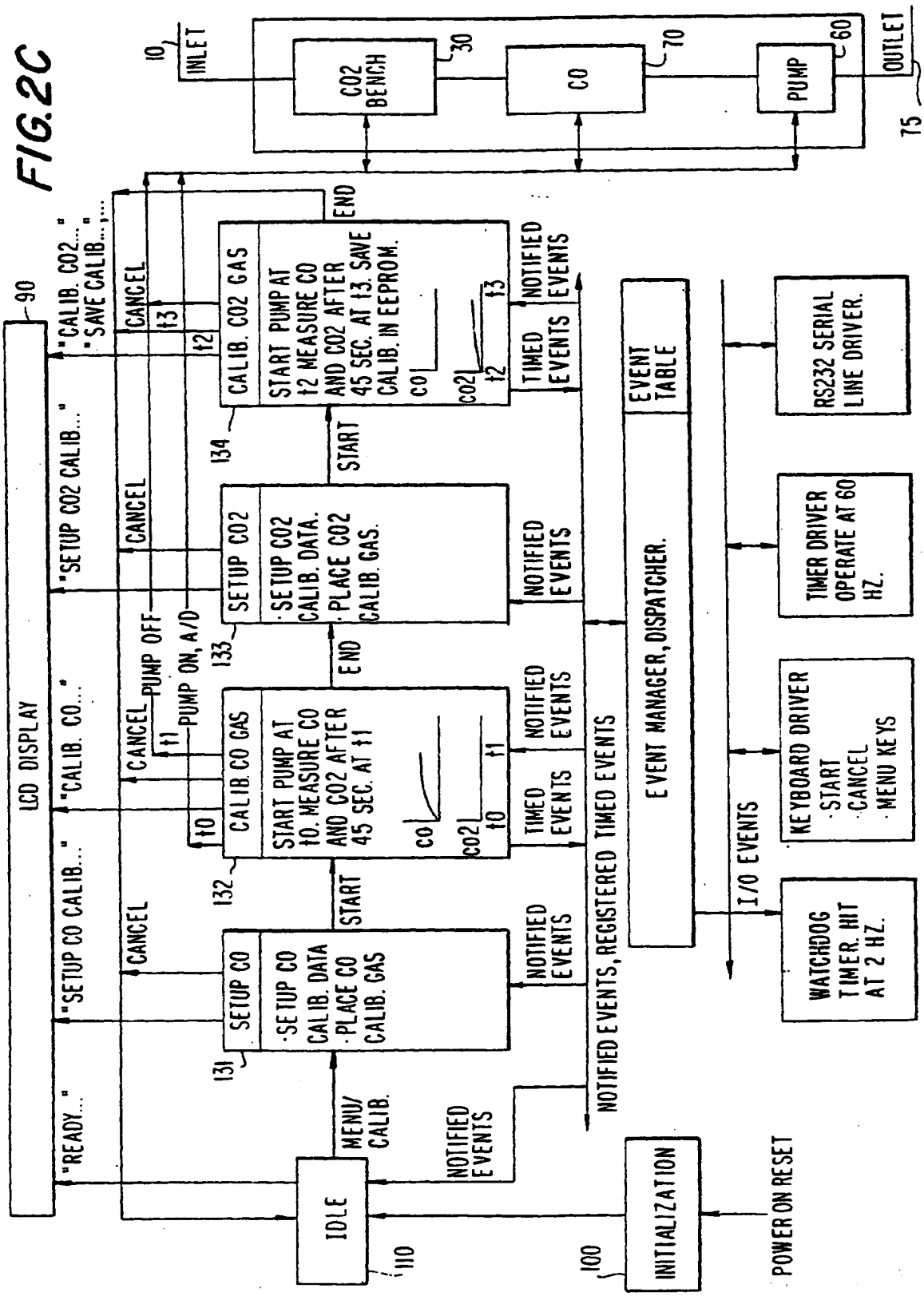

10
INLET
CO2 BENCH
30
CO
70
60
PUMP
OUTLET
75
LCD DISPLAY
90
"READY..."
"BACKGROUND..."
"PLACE NASAL CANNULA..."
"CO-11ppm,..."
CANCEL
PUMP OFF
PUMP ON, A/D
CANCEL OR 5MIN. TIMEOUT
CANCEL
t3
t2
t1
t0
R1
R2
R3
BACKGROUND
START PUMP AT t0. MEASURE ROOM CO AFTER 45 SEC AT t1.
CO
t0
t1
BACKGROUND ENDS.
PAUSE
PLACE NASAL CANNULA.
TIMEOUT AFTER 5 MINUTES.
MEASURE
START PUMP AT t2. SAMPLE CO(1HZ), CO2(30HZ) FOR 45 SEC. COMPUTE DUTY CYCLE AND BABY CO AT t3
CO
CO2
t2
t3
MEASURE ENDS.
START
NOTIFIED EVENTS
TIMED EVENT
TIMED EVENTS
NOTIFIED EVENTS
NOTIFIED EVENTS, REGISTERED TIMED EVENTS
EVENT MANAGER, DISPATCHER.
EVENT TABLE
I/O EVENTS
KEYBOARD DRIVER
· START
· CANCEL
· MENU KEYS
TIMER DRIVER OPERATE AT 60 HZ.
RS232 SERIAL LINE DRIVER.
WATCHDOG TIMER. HIT AT 2 HZ.
IDLE
110
START
NOTIFIED EVENTS
INITIALIZATION
100
POWER ON RESET

FIG.2C


10
INLET
CO2 BENCH
30
CO
70
PUMP
60
OUTLET
75
LCD DISPLAY
90
"READY..."
"SETUP CO CALIB..."
"CALIB. CO..."
"SETUP CO2 CALIB..."
"CALIB. CO2..."
"SAVE CALIB...;..."
CANCEL
PUMP OFF
PUMP ON, A/D
t1
t2
t3
t0
END
START
IDLE
110
MENU/ CALIB.
NOTIFIED EVENTS
INITIALIZATION
100
POWER ON RESET
131
SETUP CO
·SETUP CO CALIB. DATA
·PLACE CO CALIB. GAS
132
CALIB. CO GAS
START PUMP AT t0. MEASURE CO AND CO2 AFTER 45 SEC. AT t1
133
SETUP CO2
·SETUP CO2 CALIB. DATA.
·PLACE CO2 CALIB. GAS.
134
CALIB. CO2 GAS
START PUMP AT t2 MEASURE CO AND CO2 AFTER 45 SEC. AT t3. SAVE CALIB. IN EEPROM.
CO
CO2
TIMED EVENTS
NOTIFIED EVENTS, REGISTERED TIMED EVENTS
EVENT MANAGER, DISPATCHER.
EVENT TABLE
I/O EVENTS
KEYBOARD DRIVER
·START
·CANCEL
·MENU KEYS
WATCHDOG TIMER. HIT AT 2 HZ.
TIMER DRIVER OPERATE AT 60 HZ.
RS232 SERIAL LINE DRIVER.

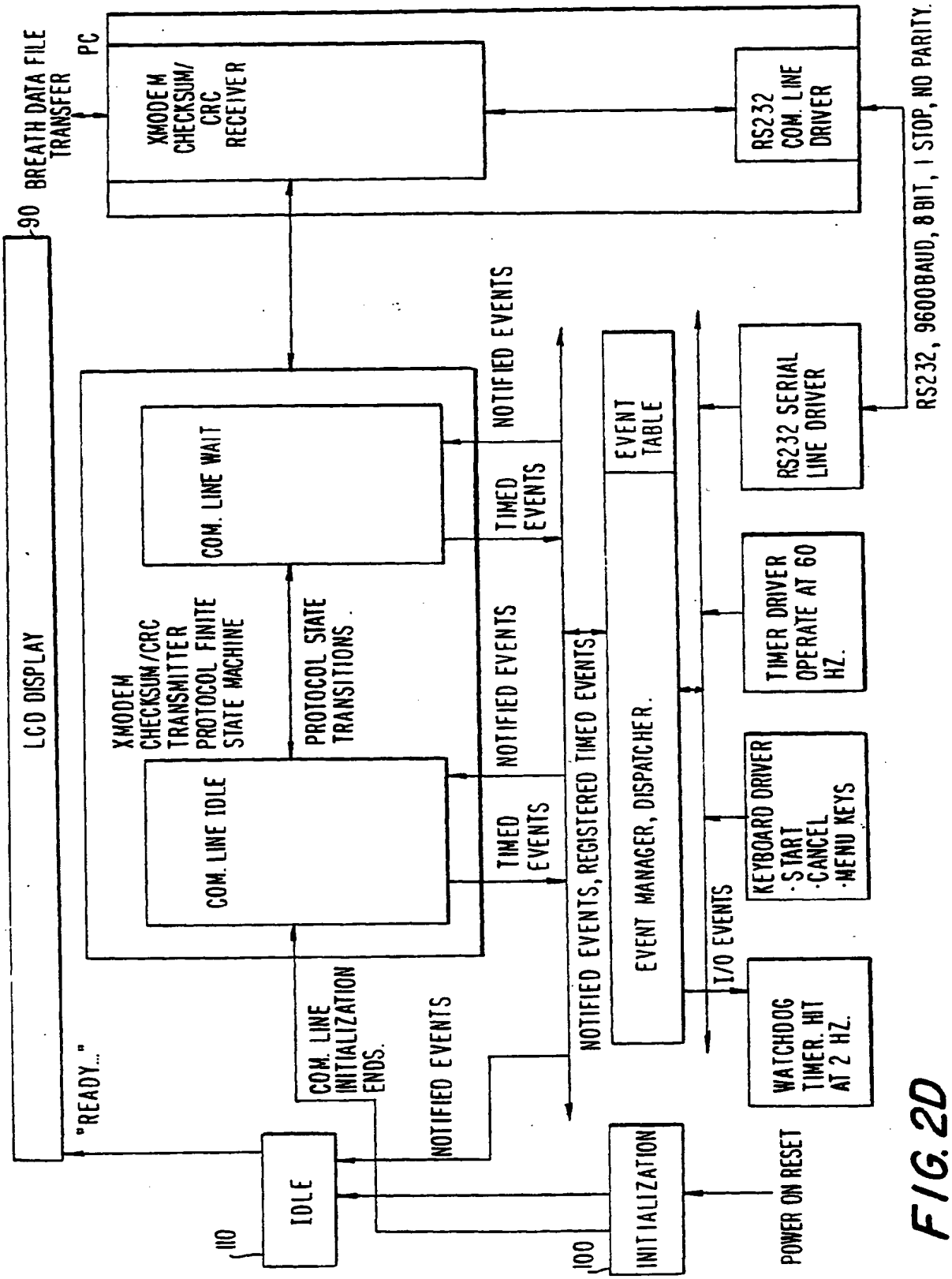

BREATH DATA FILE TRANSFER
PC
90
XMODEM CHECKSUM/ CRC RECEIVER
RS232 COM. LINE DRIVER
RS232, 9600BAUD, 8 BIT, 1 STOP, NO PARITY
LCD DISPLAY
XMODEM CHECKSUM/CRC TRANSMITTER PROTOCOL FINITE STATE MACHINE
COM. LINE WAIT
COM. LINE IDLE
PROTOCOL STATE TRANSITIONS
NOTIFIED EVENTS
TIMED EVENTS
NOTIFIED EVENTS
TIMED EVENTS
NOTIFIED EVENTS, REGISTERED TIMED EVENTS
EVENT TABLE
EVENT MANAGER, DISPATCHER.
RS232 SERIAL LINE DRIVER
TIMER DRIVER OPERATE AT 60 HZ.
I/O EVENTS
KEYBOARD DRIVER
·START
·CANCEL
·MENU KEYS
WATCHDOG TIMER. HIT AT 2 HZ.
"READY..."
COM. LINE INITIALIZATION ENDS.
NOTIFIED EVENTS
110
IDLE
100
INITIALIZATION
POWER ON RESET

FIG. 2D

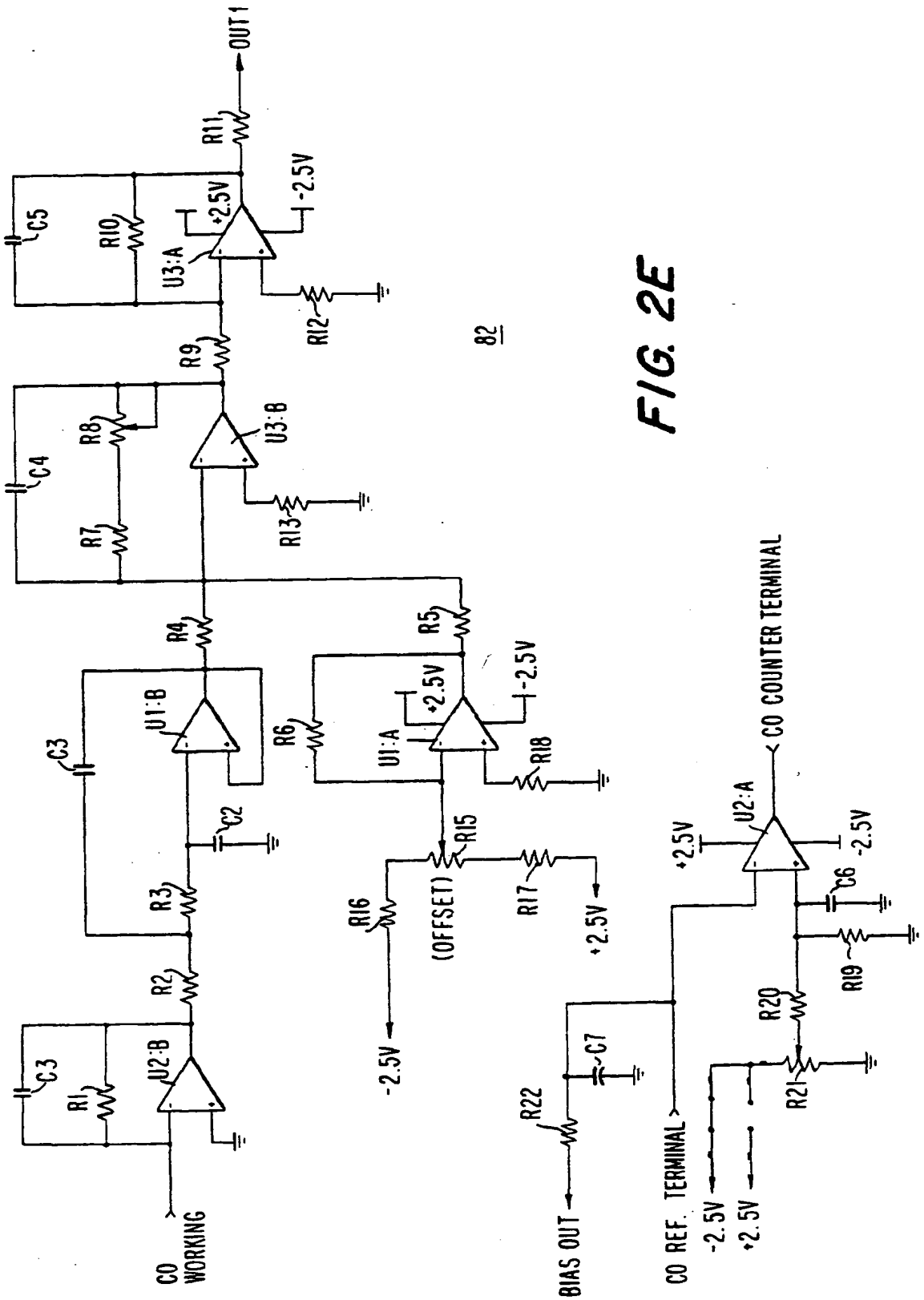

OUT1
R11
-2.5V
+2.5V
U3:A
C5
R10
R12
R9
U3:B
C4
R8
R7
R13
82
R4
R5
U1:B
U1:A
+2.5V
-2.5V
C3
R6
R18
C2
R15
R3
R16
(OFFSET)
R17
+2.5V
-2.5V
R2
U2:B
C3
R1
CO WORKING
U2:A
CO COUNTER TERMINAL
+2.5V
-2.5V
C6
R19
R20
R21
C7
R22
BIAS OUT
CO REF. TERMINAL
-2.5V
+2.5V

FIG. 2E

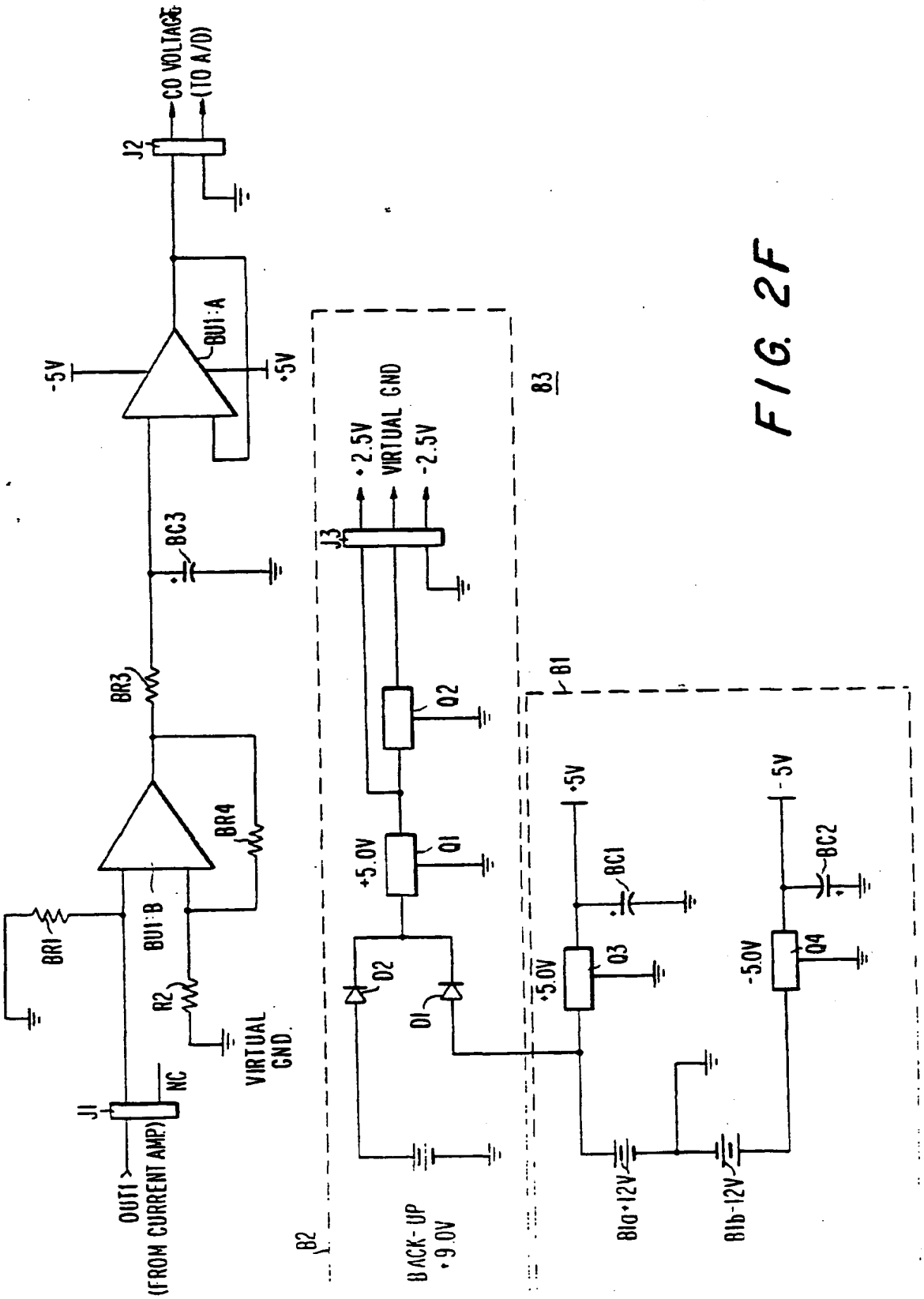

CO VOLTAGE (TO A/D)
J2
BU1:A
-5V
+5V
BC3
BR3
BR4
BU1:B
BR1
R2
VIRTUAL GND
NC
J1
OUT1 (FROM CURRENT AMP)
B3
+2.5V VIRTUAL GND -2.5V
J3
Q2
Q1
+5.0V
D2
D1
B1
+5V
BC1
Q3
+5.0V
-5V
BC2
Q4
-5.0V
B2
BACK-UP +9.0V
B1a +12V
B1b -12V

FIG. 2F

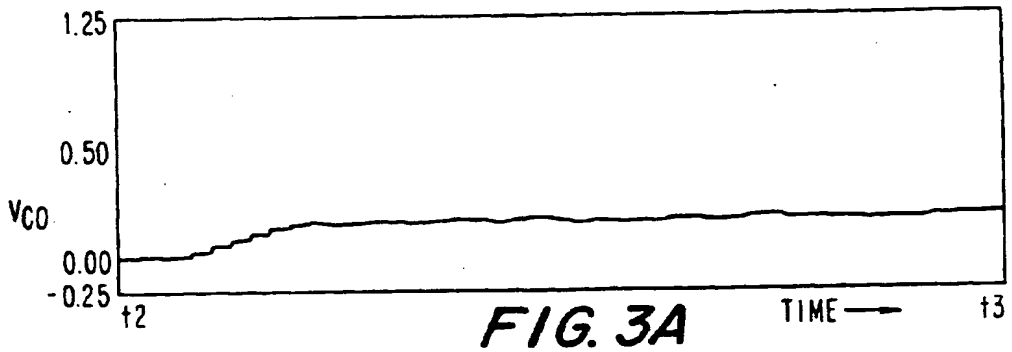


FIG. 3A

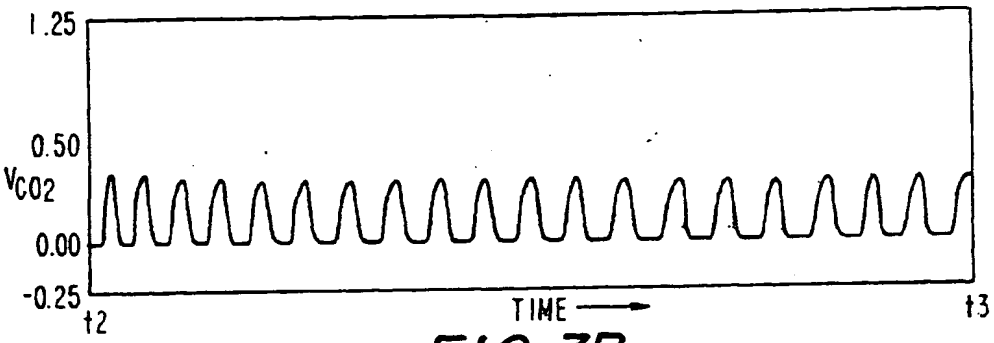


FIG. 3B

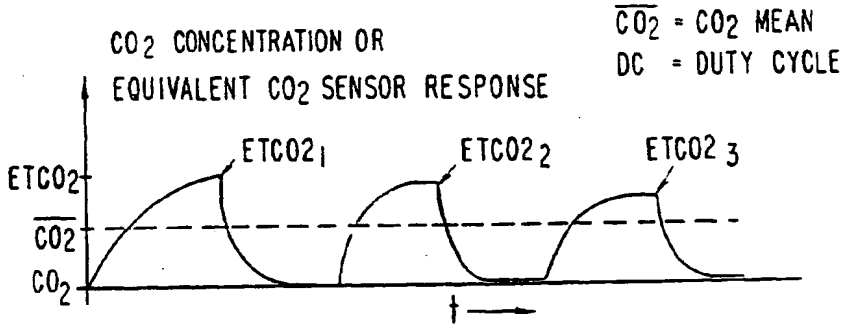


FIG. 4A

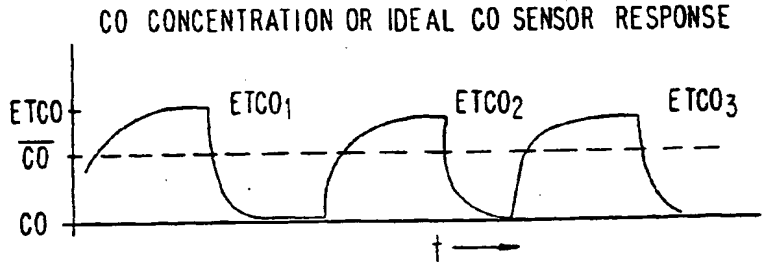


FIG. 4B

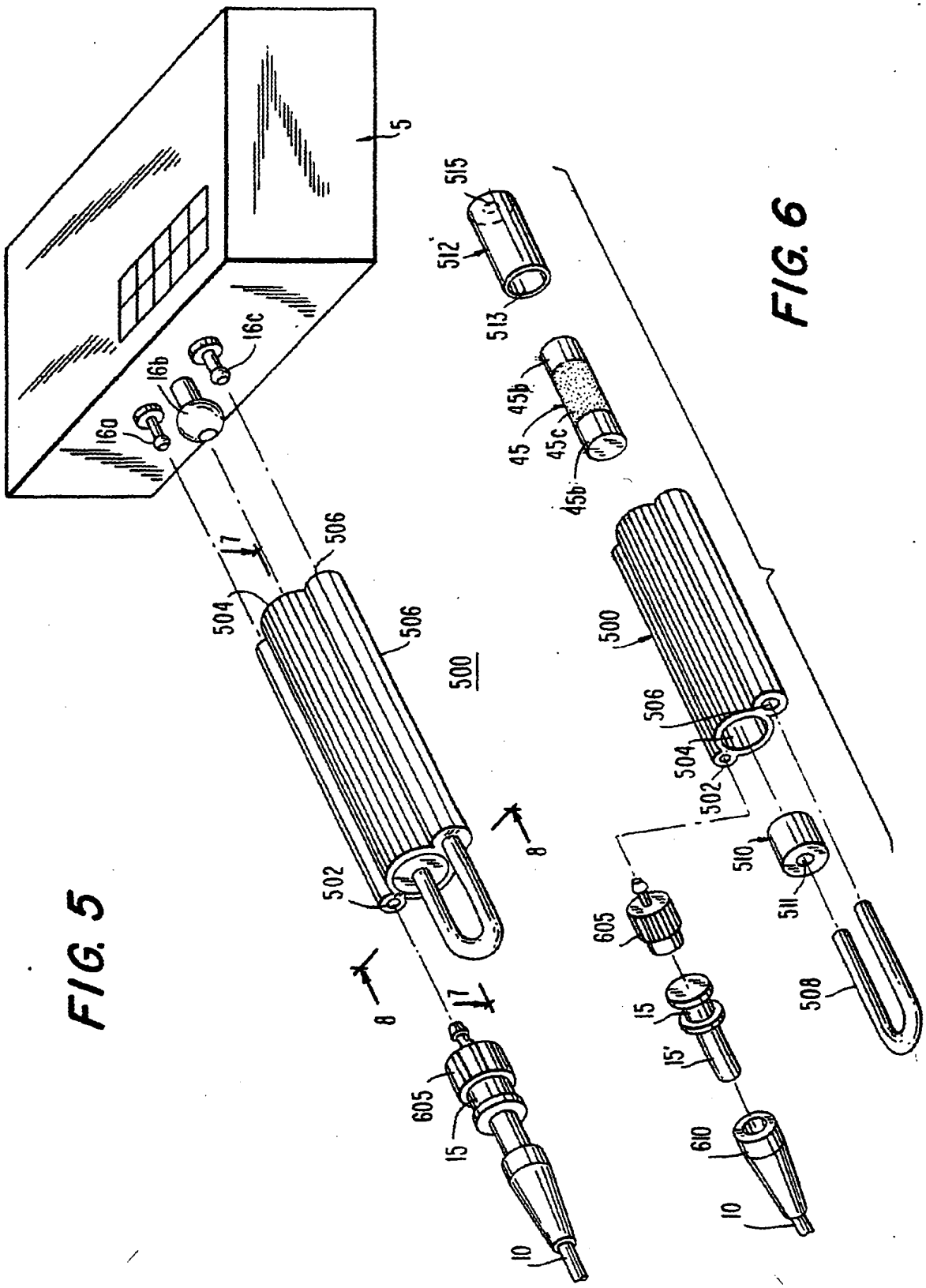

5
16a
16b
16c
17
504
506
500
502
8
605
15
10
515
512
513
45
45b
45c
15'
610
508
510
511

FIG. 5

FIG. 6

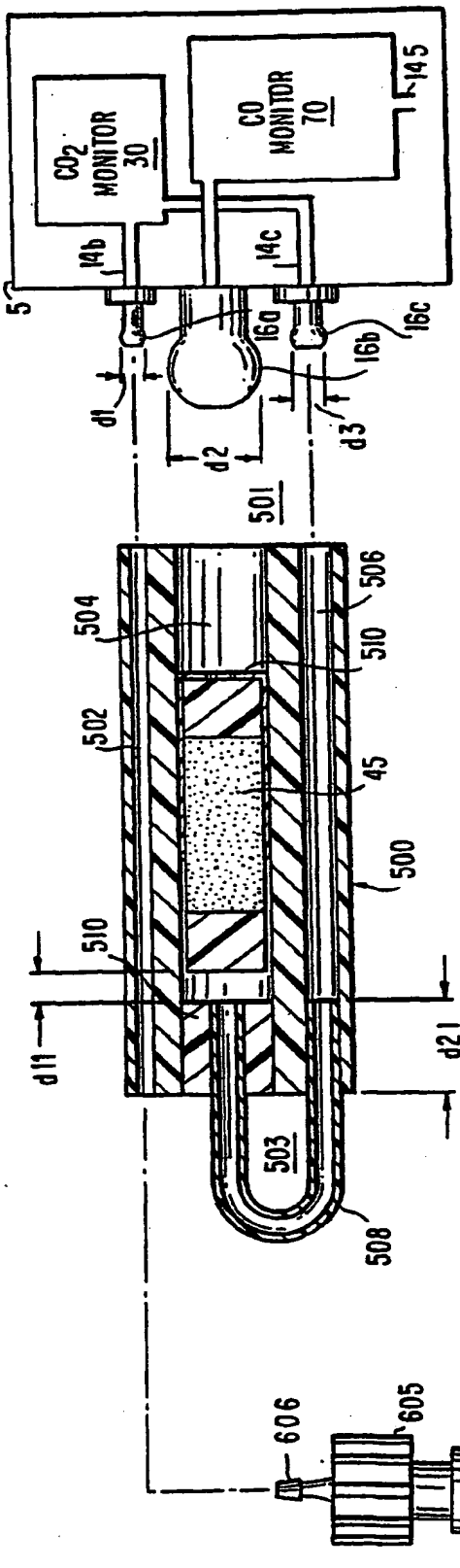


FIG. 7

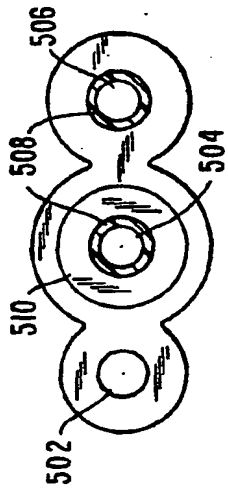


FIG. 8

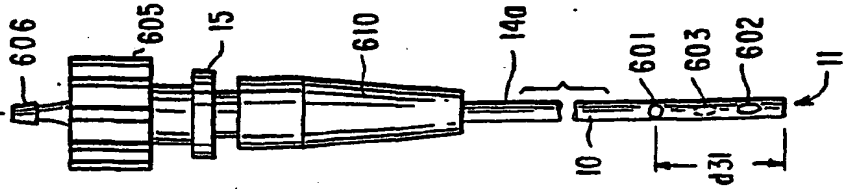


FIG. 9

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- ☐ SKEWED/SLANTED IMAGES
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